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Preliminary Estimates of Low-Frequency Sound  
Effect on Sea Animals in the Eastern Arctic

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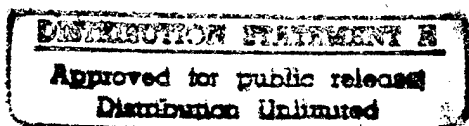
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## CONTENTS

### 1. Introduction

### 2. Results

2.1. Analysis of the literature data on aquatic mammals of the Eastern Arctic

2.2. Review of the data on auditory sensitivity, frequency range of communication sounds, and population variations of aquatic mammals of the Arctic Ocean

2.2.1. Low-frequency sound sensitivity of the auditory system of aquatic mammals of the Arctic Basin

2.2.2. Characteristics of the low-frequency signals used by Arctic aquatic mammals for sound communication

2.2.3. Seasonal variations in species, quantity, and distribution of aquatic mammals in the Eastern Arctic

2.3. Numerical simulation of transmission loss distribution of low-frequency sound in the Eastern Arctic

2.4. Estimates of potential effects of low-frequency narrow-band radiation on aquatic mammals of the Arctic Basin

2.4.1. Potential information effects of low-frequency acoustic radiation

2.4.2. Potential disturbance and annoyance effects caused by low-frequency sound radiation

2.4.3. Potential injury to aquatic mammals that can be caused by low-frequency sound radiation

2.4.4. Potential effects of low-frequency sound radiation on the aquatic animals, which are of the vital importance for aquatic mammals

2.4.5. Influence of specific low-frequency radiation parameters on the vital activity of aquatic mammals of the Arctic Basin

### 3. Conclusions

4. Recommendations concerning the applications of low-frequency radiation in the East Arctic Region and statements of research projects

### 5. References

Appendix 1. Legal data base on protection, reproduction, and rational use of aquatic mammals (pinnipeds and cetaceans) in the basin of the Arctic Ocean.

Appendix 2. Biologic-geographic characteristics of the main cetacean species of the Barents Sea

## 1. INTRODUCTION

For many years, the economic exploitation of the Arctic was confined to fishery and aquatic mammals hunting. Such activities being performed by all coastal countries lead to a considerable decrease in number of all kinds of fish and whales. Even the supplies of the regional basic fish species were depleted. This caused a serious disbalance of the ecological system: the number of bird's colonies was decreased, the food supplies of aquatic mammals was changed, which was followed by moving of seal herds from Greenland to the coast of Norway; certain changes occurred in the migration distribution, behaviour, and reproduction of the white whale.

Currently, there is no whale-fishery for most of the whale species in the Barents Sea, hunting harp seals is strictly regulated, and the white whale-fishery is forbidden.

The Arctic ecological system is highly sensitive, and, therefore, the intensive works carried on in the Barents Sea and aimed at oil and gas prospecting, drilling, extraction, and transportation (the shelf at the South and South-West side of the Kolguev island, the Shtokmanskoe deposit) may be a serious trouble. The

ecological safety of this industry is usually evaluated with relation to possible accidents and the impact they may have on the ecosystem due to oil spills and other chemical pollutants. Acoustical sea pollution due to the seismic prospecting, boring, bore-hole exploiting, oil pumping, and intense large-capacity navigation is assumed to be harmless. This is related to the fact that acoustic pollution is not obvious, and its lethal consequences can be observed only in a limited number of cases like those in the immediate vicinity (within 1 m range) of the source (pneumatic gun). But the long-term consequences of powerful low-frequency acoustic field effects, both on individual species of the ecosystem and on the ecosystem as a whole, are little studied. The recent data (part 2.4 of this report) on the visual and reproductive system impairments in fish call for the extension of research on the monitoring of the acoustic pollution.

A powerful acoustic radiation is planned to be performed for the thermometry of the Arctic Ocean. This radiation will have the central frequency of 20 - 30 Hz and sound pressure level higher than 200 dB during several tens of minutes, the radiation source being located in water over an oceanic trough, 500 km north from the line connecting the Spitsbergen island and the Franz Joseph Land archipelago. Before starting this project, it is necessary (a) to analyze the possible effects of the radiation on the Arctic ecosystem, and, particularly, on the North part of the Barents Sea and (b), at the first stage of the project named "Acoustical Thermometry of the Ocean Climate", to perform the monitoring of the biological reaction of the ecosystem on the acoustic intervention during the experiment.

The low frequency acoustic radiation in the frequency band 10 - 100 Hz falls into the range of perception of one or another sensory systems for most of the organisms (species), which belong to the Arctic Ocean biosystem: whales, especially, the Mysticeti, dolphins, pinnipeds, fish, cephalopods, molluscs, and invertebrates. If the radiation power is higher than the background noise, the radiation may cause some behavioural response (attractive-repulsive), and, when the power reaches its maximum, it may injure the organism; for instance, affect the ovules of the pinnipeds at the stage of diapause. It is also possible that the low-frequency

radiation may block the communication channels or the orientation system of some of the species, which may lead to undesirable consequences. On the other hand, it is obvious that areas subjected to high-level radiation may be limited in size, and this fact can provide some prerequisites for reasonable planning of the experiment under some restrictions to minimize the possible impact on the ecological system.

The materials presented below contain the analysis of the key biological data on the pinnipeds and cetaceans of the Eastern Arctic (section 2.1). Part 2.2 presents a consideration of the auditory system sensitivity of aquatic mammals to low-frequency sound (2.2.1), a generalization of the data on communication signal characteristics of the aquatic mammals (2.2.2), and a full representation of seasonal variations in the distribution, species structure, and numbers of aquatic mammals in the industrial area (2.2.3).

The calculations of the intensity changes of an underwater low-frequency acoustic field in the Eastern Arctic based on the given characteristics of frequency and intensity and on the given source location are presented in section 2.3. Possible influence of low-frequency acoustic radiation on aquatic mammals depending on its intensity, duration, and frequency band are considered in section

2.4. In conclusion we present the estimates of possible influence of low-frequency sound on aquatic mammals. In addition, we formulate a number of proposals on minimization of the unwanted ecological consequences and on organization and performance of biological and acoustical monitoring.

We present also a list of the legal acts of the Former Soviet Union and of the Russian Federation, which regulate the use and protection of the Arctic sea resources (Appendix 1), and a table showing the distribution of the main species of cetaceans in the Barents Sea (Appendix 2).

## 2. RESULTS

2.1. Analysis of the literature data on aquatic mammals of the Eastern Arctic

The ecological system of the Arctic Ocean (AO), on one hand, is highly vulnerable - it can be easily disturbed from equilibrium for a long period of time, for instance, in case of total industrial expansion, huge withdrawals of renewable natural resources, violation of shelf communities, and the like. On the other hand, this ecosystem "on the verge of life" is quite adaptive to the extreme conditions, and this calls for special studies aimed at the development of flexible strategies of anthropogenic actions in the cases when a large-scale human intervention into the AO system is planned to be carried out. The use of low-frequency acoustic radiation for the acoustic thermometry of the AO may have some influence on the ecosystem and its individual components. The powerful low-frequency acoustic fields, whose source is planned to be located to the North of Spitsbergen island and Franz Joseph Land, can be considered as a large-scale anthropogenic action. The influence of low-frequency acoustic radiation (LFAR) on individual components of the ocean ecosystem and on the ecosystem as a whole is poorly known. However, since the frequency range of 10 - 100 Hz falls within the perception range of certain sensory systems of the mammals, fish, cephalopods, crustaceas, and molluscs, we can assume that most of the species - ecosystem components can perceive and, hence, respond to LFAR. This fact shows the need for extended studies in this field of investigation.

Below, we represent the data on the higher links of the trophic chains of the region under consideration. Our main concern are the aquatic mammals - pinnipeds and cetaceans. We have generalized the known data on their geographic population, migrations, nutrition, and some biologic distinctive features (Vinogradov, 1949; Tomilin, 1957; Gromov et al, 1963; Kleinberg et al, 1964; Geptner, 1976). The detailed consideration of other elements of the AO ecosystem is beyond the scope of this project, and, because of this, the data on fish, cephalopods, crustaceas, molluscs, and plankton are used only in relation to the aquatic mammals feeding. The review on the data concerning acoustic signalling of pinnipeds and cetaceans is based on the monographs: Bel'kovich, V.M. and Shchekotov, M.N., Pinnipeds. Behaviour and Bioacoustics in Nature, 1990, and Bel'kovich, V.M. and Shchekotov, M.N., The Beluga Whale.

Behaviour and Bioacoustics in Nature, 1990.

#### PINNIPED

##### Common Seal (*Phoca Vitulina*)

This coastal species is of comparatively limited occurrence. It dwells in the south of the Barents Sea and at the west coast of the Spitsbergen island. This is a settled species characterized by local migrations. The seal-calves are born in June - August on shore and are able to swim starting the first day of their life. The nursing period is about one month. The coupling of seals occurs in August and only in water, (but the ovule implantation occurs 2.5 months later /diapause/ - in November). The calf food consists mainly of the bottom-dwelling crustaceans; the food for adult seals is fish, cephalopods, and crustaceans. As it was proved before, the common seals are using sound pulses for sounding. The basic frequency range does not exceed 7.5 kHz. Signals having a definite communicative meaning were detected during a contact between a seal-calf and his mother and consisted of three individual sounds characterized by the basic frequency 3.8 kHz and 4 - 7 harmonics.

Pulse series of a basic frequency up to 1 kHz and a varying rate were produced by the animals in the state of aggression.

##### Grey Seal (*Halichoerus Grypus*)

This species is also of limited occurrence and dwelling only at the south-west coast of the Barents Sea. This seal is characterized by a settled way of life. The calves appear in autumn - September to November (the peak is in the middle of October). The nursing period lasts 2 - 3 weeks, and the calves stay ashore for several weeks. The reproduction occurs during the same period, and the ovule implantation occurs 100 days later. The food is based on fish and, to a lesser extent, on crustaceans and molluscs.

The sounds produced by the grey seals were recorded in a pool. Pulse signals were detected that were characterized by a frequency of 12 kHz, intervals between the pulses in pairs 0.01 - 0.2 s, and repetition rate in series 70 - 80 pulses per second. The individual components frequencies of the signals were up to 30

kHz. The signals carried some communicative content, because they were produced by the animals only during their social contacts.

#### Harp Seal (*Phoca Groenlandica*)

This species is quite popular. It forms three populations - the Newfoundland, Jamaica, and White Sea populations. This species is widely migrating. The reproduction of the White Sea population occurs on ice in the White Sea from February to May. The calves appear in late February - early March and are nursed for two weeks, then, after their shedding of hair, they go to swim. Coupling of seals occurs during the same period of time, and the ovule implantation is in June. As the ice is breaking, the Harp Seals move to the Barents Sea. They shed their coats on ice, and then they begin their active food hunting migrations to the East along the coast, to the ice edge, to the coast of the Novaya Zemlya, in the Kara Sea, to Franz Joseph Land, and to the Spitsbergen island. The young seals eat mostly the surface-dwelling species of small-sized crustaceans and fish, and the adult seals eat also some of the deep-water fish, crustaceans, and cephalopods.

During coupling, the male seals produce underwater sounds, which are assumed to play an inviting role. The sounds used for underwater communication by the harp seals were described in literature. The signals were radiated singly or in groups. The basic frequency of these signals covered the range of 0.5 - 10 kHz, and their duration could vary from 0.12s to several seconds.

#### Hooded Seal (*Cystophora Cristata*)

This inhabitant of the North Atlantic is a quite numerous and widely migrating species. During his food hunting migrations he reaches the region of the Spitsbergen island and the west and south-west parts of the Barents Sea, where he can be found in autumn and in early winter. The hooded seal is a perfect swimmer and diver, hence, his food includes different types of pelagic and bottom-dwelling fish, cephalopods, and crustaceans. His all-yearlong feeding is most intense in spring after breeding and in autumn and winter, after shedding of hair and before breeding in the second



half of March. In this period of time, the male seals are producing loud sounds, in air and in water, by using the resonators of their nasal bags, which can be significantly increased in size.

In captivity, the hooded seal produced clicks in the frequency range 0.1 - 16 kHz with different basic frequencies. Other researchers recorded underwater sounds from the male hooded seals in a lower frequency range of 0.1 - 1.2 kHz and with harmonics up to 3 - 6 kHz.

#### Bearded Seal (*Erignatus Barbatus*)

This species being quite numerous, is characterized by a circumpolar distribution, and belongs to the regions no deeper than 150 m. His basic food are bottom-dwelling invertebrates, mostly, mollusca and crustaceous, and fish. The bearded seal was repeatedly registered to the north of Spitsberegén island, Franz Joseph Land, and Severnaya Zemlya island. This species is common for the edge of ice and unfrozen patches of water in the midst of ice, hundreds kilometers far from the edge of ice. He builds a system of wholes in ice for breathing and arranges his lairs in the hummocks, which is similar to the behaviour of the ringed seal. Migrations of the bearded seal in the East Arctic are poorly known. We think that his distribution is determined by the sufficient food supplies, and, consequently, this species is of a resident type, and a certain part of it dwells all year long in the area of the Arctic islands, together with the ringed seal. The seal-calves are born in March - May. Some scientists believe that the calves are born on ice, but our data testify that they are born only in the lairs, like the ringed seal calves.

Lactation lasts 2 - 3 weeks and is followed by coupling, and the implantation of blastoint occurs after 2 months.

During the period of reproduction, the male bearded seals produce numerous long frequency-modulated signals, practically, twenty four hours a day (Bel'kovich and Shchekotov, 1990).

The sounds produced by the bearded seals are extended frequency-modulated warbles of 1 min. duration, dropping in frequency from 2 - 3 kHz to 200 Hz, and serve for territorial and reproductive purposes. A low-frequency non-modulated groan lasting 2 - 3 s

often follows the warble after 15 s of silence.

#### Ringed Seal (*Phoca hispida*)

The most arctic species of circumpolar distribution is found to the north from the latitude 84.5 deg. north. This species is common in the unfrozen patches of water of pack ice at the coasts of the Arctic islands and of the mainland. The calves are born in special lairs in March - June and are nursed during 5 - 7 weeks.

The coupling occurs after the termination of the lactation period, and the ovule implantation occurs 2.5 months later. The adult Ringed seals stay on coastal ice during the period of reproduction, while those who are not taking part in the reproduction process are found at the edge of ice and on the drifting ice fields. After the shedding of hair is over, the ringed seals of all ages take part in food hunting migrations and concentrate in the polar front waters. Their main food is fish and crustaceans.

The registration of the underwater sounds of these animals in captivity revealed the presence of single and paired pulse signals in the frequency band up to 4 kHz with the intervals between the signals in pairs 2 - 20 ms.

Aggressive and submissive vocalization of these animals is represented by the signals, which have the basic frequency in the range of 1 - 3 kHz and harmonic constituents up to 6 kHz. The signal duration was varying within 0.2 - 0.5 s.

#### Walrus (*Odobenus Rosmarus*)

The species is characterized by a circumpolar distribution and is represented in the region under consideration by three populations - Chukotka, Laptev - in the Laptev Sea, and of the Novaya Zemlya, which are dwelling in the Barents Sea and the Kara Sea. The Walruses are dwelling in the zone of the drift pack ice in the sea regions of depths not exceeding 80 m. In summer, they form on-shore seal-rookeries, whose locations remain unchanged from year to year. The walruses are highly gregarious animals, the age and sex structure of their groups varying over the course of a year. The calves of the Novaya Zemlya walruses are born in late De-

cember - January, and in other populations they appear in April - May. A calf is nursed for about two years. The coupling occurs in January - March and is accompanied by numerous signals produced by the males.

The ovule implantation occurs 4 - 5 months after coupling. The nutrition of the Walruses is based on the benthos organisms - bivalve mollusca and crustaceous, worms, fish, starfish, and, sometimes, other aquatic mammals (ringed seal). The details of the walrus migrations in the East Arctic are poorly known. According to the present concept, in the Barents Sea, in summer, they move north with the drifting pack ice fields, and in autumn they move with the ice back to the south, never being found in the central deep sea regions. In the Kara Sea and in the Laptev Sea the situation is reversed. In summer, the walruses show up in the southern regions (Raidaratskaya Inlet, Coast of M. Pronchishchevoi), and in autumn they are moving northward.

The walrus produces a variety of underwater sounds. They include series of clicks of 0.015 - 0.02 s duration with the basic frequency of 400 Hz and the pulse rate up to 10 pulses per second; gnashing starting with 4 - 10 pulses, each of them having the basic frequency of 400 - 600 Hz and duration 0.1 s. If the signal lasts 1 - 2 s, its intensity and pulse rate increase by the end of the signal, which results into an almost continuous sound of basic frequency 200 - 300 Hz; powerful bell-like sounds of frequency 0.4 - 1.2 kHz and duration 1 - 1.5 s; pulse series of frequency up to 4 kHz and of varying intensity.

Stereotyped and repeated series of sounds are produced mainly during the reproduction season and play an important role in courting and, probably, in individual recognition and maintenance of underwater territories.

#### CETACEANS

Large whales are represented in the Eastern Arctic by seven species - the right whale, the sperm whale, and even the *Eubalaena Glacialis* can be found near the Spitsbergen Island. These species are characterized by long-range seasonal migrations, and the time they spend in the Arctic is limited to the summer - autumn season.

Among all the whales, only the right whale comes to the drift ice region and can be found far away from the edge of ice. The basic food for the *Eubalaena Glacialis*, blue whale, and sei whale are pelagic crustaceans. The fin whale, minke, and humpback whale eat fish as well. The male sperm whale, who reaches the high latitudes, are eating cephalopodan mollusca and bottom-dwelling fish. The summer migrations to the north for these species are related to the sharp increase of food supplies at the polar front during this period. For most of the species, the birth of calves and coupling occurs in the temperate and mild waters in winter.

#### *Eubalaena Glacialis*

The number of the whales of this species is extremely small. Before, these whales were registered in the Barents Sea, and, currently, they may stay for summer in the sea region to the west of the Spitsbergen Island. Their food consists exclusively of small-sized plankton-type crustaceans.

The acoustic signalling of the *Eubalaena Glacialis* is represented by low-frequency sounds of frequencies up to 0.4 kHz.

#### Right Whale (*Balaena Mysticetus*)

The species is of limited occurrence in the Atlantic sector of the Arctic and more popular in the Pacific sector. In the East-Siberian Sea these whales are uncommon, and, in the Laptev Sea, they were never registered. In spring and summer, these whales were found up to the latitude 80.5 deg. north near the Spitsbergen, Franz Joseph Land, and Novaya Zemlya islands. They penetrate far into the fields of drift ice and use cracks and unfrozen patches of water for breathing; sometimes, this whale breaks young ice with his back. The right whale eats the crustaceans and pteropoda mollusca. The biology of this species is poorly known. The reproduction occurs in the late winter and spring among the ice. The total number of right whales in this region does not exceed, according to some estimates, dozens of animals, or, according to other estimates, several hundreds of animals.

The right whales produce signals in the form of low-frequency

narrow-band screams of the duration 1 - 2 s.

#### Blue Whale (*Balaenoptera Muskulus*)

It is not a numerous species. The whole Barents Sea is included into his usual area of distribution during the period of June - August. This species can move north, up to the latitude 80.5 deg. north, to the edge of ice near the Spitsbergen island. The number of population is estimated somewhat higher than for the right whale, although, in both cases the data are fairly scanty. This species is typical for deep-sea regions and often attached to the front zones, where he eats, mostly, small-sized crustaceans.

The sound signals of the blue whales are of a great variety. Among the broad spectrum of these signals, both location signals and communication signals are registered. Different "moans" with the mean dominant frequency of 90 Hz and pulse inclusions of 20 - 2000 Hz. Sharp broadband sounds produced during the spring migrations in the frequency range 100 - 3500 Hz, with the intensity 175 - 185 dB (with respect to 1 micro-Pa at the distance of 1 m), song-resembling sounds of frequency 20 - 5000 Hz and groans of frequency 25 - 900 Hz, low-frequency and frequency-modulated screams in the frequency band of 12 - 200 Hz and duration 36.5 s.

#### Fin Whale (*Balaenoptera Physalus*)

This species has a tendency to decrease in number. In the Barents Sea, he is registered regularly to the south from the Spitsbergen island during the April - September period. His food includes both pelagic crustaceans and fish. In winter, most of the whales are moving south, but sometimes they can be seen in winter in the Barents Sea. This whale is uncommon at the coast of Novaya Zemlya; in the Kara Sea, he shows up incidentally, but reaches the Ob Inlet and the Yenisei Gulf (Tomilin, 1963). The number of this population is estimated as 2 - 2.5 thousand animals.

The Fin Whales radiate different underwater signal series consisting of pulses of dropping frequencies (23 - 18 Hz) and duration about 1 s. The upper level of the radiation intensity reaches 186 dB (relative to 1 micro-Pa at the distance 1 m). In the

presence of several whales, pulses of frequencies 17, 18.5, 19, 20, and 40 Hz were registered, which were likely to be intended for identification. Communicational meaning is ascribed to the sounds of frequencies 0.1 - 30 kHz and duration 0.3 s.

#### Sei Whale (*Balaenoptera Borealis*)

These whales are more heat-loving and appear in the Arctic only sporadically reaching the latitude 72.5 deg. north. They appear there in summer, near the islands of Spitsbergen and Novaya Zemlya. Their food includes a variety of forms (small crayfish and fish), which allows them to stay both in the coastal and in the deep-sea regions. The number of these whales was estimated as 1.4 - 2.2 thousand heads.

The registration of the sei whale signals revealed the presence of click series (7 - 10) having the maximum energy at a frequency of 3 kHz. Signals of 20 Hz frequency were also registered, but only in the presence of some other species, and, hence, they can not be ascribed to the sei whales with certainty.

#### Minke (*Balaenoptera Acustovostrata*)

The number of this species was decreased because of too much fishing, but he is still widespread in the Barents Sea, especially, in its southern and western regions. The minke is also common near the edge of ice. His food consists mainly of fish - herring, cod, and other, and in the high latitude regions - pelagic crustaceous. The whales can be found singly or in pairs, groups are uncommon, the females with calfs never go far north.

The sounds produced by the minkes include both signals characterized by dropping frequencies (130 - 60), duration about 0.2 - 0.3 s, and intensity up to 165 dB (relative to 1 micro-Pa at 1 m distance) and groups of short series and clicks within the frequency range 3 - 12 kHz. The duration of these signals lies within 0.5 - 1 ms.

#### Humpback Whale (*Megaptera Novaeangliae*)

The species is of limited occurrence, and can be found mainly in the western part of the Barents Sea in spring, summer, and autumn. Any visits of these whales to the north-eastern or central regions of the Barents Sea were never registered. The whales usually can be found singly or, sometimes, in pairs consisting of two adults or a female with a calf. The food is mainly pelagic crustacea and common fish species: cod, herring, and others.

The variety of sounds produced by the humpback whales includes low-frequency screams in the frequency range 120 - 300 Hz of 0.5 - 1.5 s duration and screams of higher frequencies (4 - 8 kHz). The intensities are 124 - 155 dB (relative to 1 micro-Pa at 1 m distance). While a humpback whale was fed, sounds of frequencies 20 - 2000 Hz were registered. The state of excitement and aggression was accompanied by signals of higher frequencies (up to 10 kHz), although the dominant frequency did not exceed 2 kHz. The meaning of the songs of the humpback whale is not yet clear, these songs consisting of repeated sound series of frequency no higher than 4 kHz and duration up to 36 min.

#### Sperm Whale

Only the males of this species can be found in the Arctic water areas in summer, and, mostly, they appear in the western part of the Barents Sea and near the Spitsbergen island. Their basic food are the cephalopods. When scattered during their prolonged diving in groups, the sperm whale are using long series of clicks consisting of separate pulses. The frequency range of the clicks lies within 30 Hz to 30 kHz. Because the signals radiated by the animals possess individual features, they are considered to be used both for sounding and for communication.

#### Killer Whale (*Orcinus Orca*)

These whales are common in the south-west region of the Barents Sea in summer and autumn, though, they may be found near the Spitsbergen island and Novaya Zemlya island, and, sometimes, in the Kara Sea. At the extreme points of their propagation, the killer whales usually can be found in groups of 2 - 4 whales. The

reproduction takes place all year long, reaching its maximum in late autumn and winter. The basic food of these whales is fish, but it was found, that they eat sometimes the warm-blooded animals (pinniped and cetaceans).

The study of underwater signalling of four separate groups of killer whales determined three types of signals. One of them, represented by whistles of the basic frequency 1.5 - 18 kHz and duration 50 ms to 10 - 12 s and pulse screams of frequency 1 - 6 kHz and duration 50 ms to 10 s, can be considered as serving for communication.

#### Bottlenose Whale (*Hyperodon Ampullatus*)

This species prefers the deep-sea regions, in particular, the bottom hollows near the Spitsbergen island, where he is staying during the spring and summer season. Usually, these whales hold together in groups. They were seen near the Novaya Zemlya island and in the central region of the Barents Sea. Their food consists mostly of cephalopods, but some fish was also registered. He can dive hundreds of meters deep and stay under the water surface up to 60 minutes.

The communication signals of the bottlenose whale were registered from three groups of whales in the form of whistles having the maximum energy at frequencies 3 - 6, 7 - 9, and 12 - 14 Hz. The signal duration was within 115 - 850 ms.

#### Harbour Porpoise (*Phocoena Phocoena*)

This species is fairly numerous in the western and southern regions of the Barents Sea. Small numbers of these whales were registered sporadically along all the southern coast of the Barents Sea and even in the Kara Sea. The way these whales are moving is determined by food hunting in the shelf zone. The reproduction occurs in May - July.

The common porpoise radiates low-frequency pulses with the basic frequency not exceeding 2 kHz of the duration 0.5 - 5 ms. In stress situations, the whales produce squeals of frequency 0.4 - 4 kHz and duration 0.02 - 1 s and peeps of frequency 1.2 - 3 kHz and



duration 20 - 30 ms.

In captivity ultrasonic echolocation pulses were recorded with peak frequency over 100 kHz.

#### Beluga Whale (*Delphinapterus Leucas*)

The Beluga whale is a permanent resident of the Arctic Ocean, and it is quite numerous. As the observations showed, the herds of thousands whales move in a complicated way in space and time: in the southern coastal region of the Barents Sea, in the inlet of the White Sea, in the Kara Gate, and near the Spitsbergen island. At the same time, in some places (the White Sea), a number of practically settled populations of the white whales can be found.

The behaviour of the white whale is quite flexible, which allows him to be fed by various types of fish: bottom-dwelling and pelagic, single and in shoals. The calfs are born in May - August, the nursing period is about a year. The regions where the whales stay in winter are poorly known. The white whale is well suited for life among the ice fields and was registered many times in the unfrozen water patches in the midst of ice rated 8 - 9 in the Kara Sea, between the islands Novaya Zemlya and Severnaya Zemlya and in some other places (Bel'kovich, 1960). This fact suggests that, in the case of sufficient food supplies (fish), this species may be found in winter in the high latitude regions.

The sound activity of the Beluga whales was studied by many scientists, whose results agree well with each other. These studies reveal a wide variety of communication and emotion signals of the whales. The dominant frequencies of these signals cover the frequency range 0.2 - 13 kHz. The duration of signals, pulse series, and pauses may be varied over a wide range.

#### Monodon Monoceros

The distribution of this species is circumpolar in the high-latitude region of the Arctic Ocean, to the north from the edge of the drift ice, near the islands: Spitsbergen, Franz Joseph Land, Novaya Zemlya, Severnaya Zemlya, DeLong's, and Vrangell'. The mig-

rations of these whales are related to the movement of sea icesouth in winter and north in summer. The biology of this species is much like the biology of the Beluga whale. In particular, this is true for the structure of the herd population, which includes smaller separate herds of adult males, females with calves, and others. The data of the observations provide the number of these whales of 10 - 15 thousand heads.

Acoustic signalling of this species is less studied than that of the white whale and can be considered only on the basis of a few observations (records). The signals of the Monodon Monoceros are less variable and of higher frequencies.

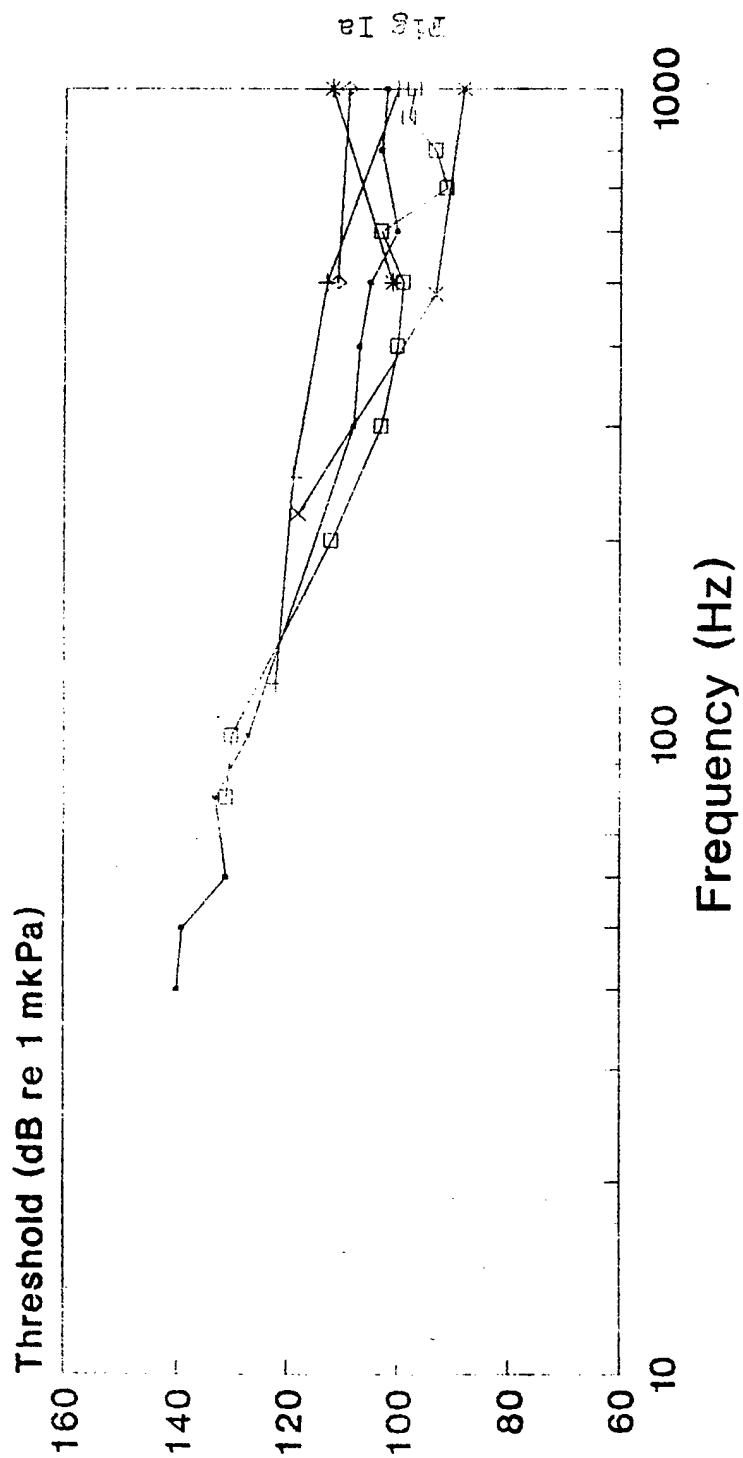
Mostly, pulse signals were studied consisting of series of varying spacing frequency. The duration of series is about dozens of seconds, and the duration of the pulses may vary from dozens of microseconds to about 4 ms. The signals have narrow-band spectra. The dominant frequency peak is at 40 kHz and the second peak, smaller than the first one, is at 20 kHz. A negligible part of energy accounts for the audio frequencies. The levels of sound radiation may reach 200 - 218 dB at the distance of 1 m.

Communication sounds of lower frequencies with a pronounced frequency modulation were also recorded.

## 2.2. Review of the data on auditory sensitivity, frequency range of communication sounds, and population variations of aquatic mammals of the Arctic Ocean

### 2.2.1. Low-frequency sound sensitivity of the auditory system of aquatic mammals of the Arctic Basin

Most of the aquatic mammals possess highly developed auditory systems. Toothed whales are very sensitive to signals in the high audio and ultrasonic frequency ranges, where the absolute thresholds reach the values of 40 dB. Most of the toothed whales are using active hearing mechanisms for sounding. The highest auditory sensitivity of the pinniped was observed at frequencies 2 - 20 kHz and equals 60 dB.



Johnson et al, 89    Awbrey et al, 88    Andersen, 1970  
 Johnson, 68    Schusterman et al, 72    Babushina et al, 92

The hearing of aquatic mammals in the low-frequency range, which is of interest for us, has not been sufficiently studied. Figure 1a shows the low-frequency sections of audiograms obtained for the Beluga whale (Awbrey et al, 1988, Johnson et al, 1989), the bottlenose dolphin (Johnson, 1968), and the harbour porpoise (Andersen, 1970). We should note that the most detailed results were obtained for the Beluga whale - the most numerous whale of the Arctic Basin. Starting with the data available, we can assume that the thresholds of hearing of the toothed whales are increasing uniformly from 120 - 125 dB at frequency 100 Hz to 145 - 155 dB at frequency 10 Hz. The assumption of a smooth increase of the thresholds of hearing in the infrasound frequency range is based on the general shape of the curves.

There are even less data on the low-frequency auditory sensitivity of pinniped in water. The absolute thresholds for frequencies below 1 kHz, which were determined by a behavioural method for the californian sea lion (Schusterman et al, 1972) and the northern sea bear (Babushina et al, 1992), are also presented in Fig. 1a. These fragmentary data suggest a hypothesis that the sensitivity of the pinniped in the infrasound frequency range should be similar to the one of the odontoceti whales.

Of special interest for us is the study of the auditory sensitivity of mysteceti, which are the most likely object of the low-frequency sound effect. There are no experimental audiograms known for these animals. Since the direct estimates of the thresholds of hearing are impossible, we have to restrict ourselves by the indirect behavioural and morphologic data.

Some authors observed that the whales are able to hear the communication sounds of both their own species (Tyack and Whitehead, 1983) and of the assumed beast of prey (Malme et al, 1983) at distances of many kilometers long. The well-defined behavioural responses of the mysteceti to the signals of an approaching vessel were registered at such long distances that the signal spectrum should contain mostly the low-frequency components, the total level being about 110 dB (Malme et al, 1989).

Significant information can be provided by the morphologic data. The studies of the middle and internal ear structures performed on the present mysteceti species (Fleischer, 1978, Norris

and Leatherwood, 1981) and on some of the extinct species (Fleischer, 1976) testify to the high auditory sensitivity of the mysteceti to low-frequency sound.

The internal ear morphology of the mysteceti whales was studied most comprehensively by D. Ketten (1993). According to her data, the width of the basilar membrane of a fin whale is varying from 0.1 mm in its basal part to 2.2 mm in its apical part. This is approximately three times as large as a human basilar membrane, which indicates to the low-frequency tuning of the hearing system of the animals. Some kind of speculative estimates based on the measurements of the mechanical characteristics of the basilar membrane enable us to assume that the mysteceti display the highest auditory sensitivity in the range of 10 - 100 Hz.

Table 1 shows the data on the numbers of the auditory nerve fibres in several odontoceti and mysteceti whales (Morgan and Jacobs, 1972) and also in typical, land mammals. On the assumption that the mysteceti have no developed high-frequency sounding system, we can see that the results indicate once more, indirectly, to the existence of a highly developed low-frequency hearing of the mysteceti whales.

Physiological methods (above all, registration of the evoked potentials of the brain stem) are not used, so far, for studies of the hearing abilities of the mysteceti whales, while they were used successively for the odontoceti in the high frequency range (Popov and Supin, 1990, Bibikov, 1993). The current development of the registration methods and telemetry makes it possible to set the task of performing such experiments in the near future.

On the whole, the data available by now make it impossible to ignore the hypothesis of the rather high absolute sensitivity of some of the aquatic mammals of the Arctic Basin (above all, the mysteceti) in the low-frequency audio and infrasound frequency ranges.

However, even if we consider the highest possible sensitivity of the hearing system, we should take into account that sound detection is performed against the background of the sea noise, whose level at frequencies of dozens of Hertz is usually quite high. The main constituents of the sea noise in the Arctic Basin in this frequency range are: 1. noise from the remote ship traffic reac-

hing the level of 100 dB relative to 1 micro-Pa in the onethird-octave band with a maximum at about 50 - 100 Hz; 2. noise from remote seismic events (micro-earthquakes) reaching 110 - 120 dB in the one-third-octave band with a maximum at 6 - 30 Hz (Keenan and Dyer, 1984); 3. noise due to ice field formation (Buck and Wilson, 1986) reaching 120 - 130 dB near the source and having no pronounced spectral maximum; 4. noise due to the turbulence of the oceanic streams, their level dropping with increasing frequency starting from 4 - 6 Hz, but, even at frequencies 20 - 30 Hz, being able to reach 120 - 130 dB in the one-third-octave band (Wenz, 1962).

The experimental data demonstrate that the typical mean total noise level of the Arctic Ocean and the northern part of the Atlantic Ocean in the frequency range of 10 - 100 Hz is about 100 dB in the one-third-octave band, or 85 - 90 dB over 1 microPa/Hz (Perrone, 1974, Kibblewhite and Johnes, 1976, Miles et al, 1986). We should note, that measurements of the underwater noise level in the Arctic Basin at the 50 Hz frequency revealed variations of this level within more than 15 dB from day to day (Greene and Buck, 1964).

The problem concerning the threshold of detection of a tone signal on the noise background comes to the problem of estimation of the auditory filter width of aquatic mammals. This parameter was studied only for the odontoceti (Johnson, 1968,b, Johnson et al, 1989). According to the last-mentioned study, the critical ratio for the Beluga whale at frequencies below 0.1 kHz is about 18 dB. This means that, if the spectral density of a broadband noise is 80 dB/Hz, the threshold of tone detection will be 98 dB. By extending this estimate (which is close to the data obtained for humans) to the case of mysteceti we can come to a following conclusion: the experimental data make it impossible to ignore the assumption that, under a weak sea noise, the mysteceti will hear the signals of frequency 20 - 30 Hz and of levels not exceeding 100 dB relative to 1 microPa.

Table 1

Bottlenose Dolphin	- 67,900	Morgan and Jacobs, 1972
Harbour Porpoise	- 50,000	Morgan and Jacobs, 1972
Inia	- 72,000	Morgan and Jacobs, 1972
Beluga Whale	- 102,000	Morgan and Jacobs, 1972
Humpback Whale	- 107,000	Morgan and Jacobs, 1972
Fin Whale	- 92,000	Morgan and Jacobs, 1972
Human	- 30,000	Harrison and Howe, 1974
Macaco	- 30,000	Harrison and Howe, 1974
Cat	- 50,000	Harrison and Howe, 1974

2.2.2. Characteristics of the low-frequency signals used by the Arctic aquatic mammals for sound communication

We do not consider in detail the characteristics of sound radiation of odontoceti and pinniped, because the communication signals typical for these animals fall within the frequency range above 1 kHz and the ultrasonic range. Signals of frequencies below 100 Hz are uncommon for these animals. But there are some low-frequency pulses, which accompany the echo-signals of dolphins (Giro and Dubrovsky, 1974), some low-frequency whistles of the Beluga whale (Sjare and Smith, 1986, Bel'kovich and Shchekotov, 1990, 1993), and fairly active acoustic low-frequency communication between a number of pinniped (Schewill et al, 1963, Thomas and Kuechle, 1982, Hanggi and Schusterman, 1993) including the species found in the zone affected by the infrasound radiation.

To the west of the Franz Joseph Land, signals from the Monodon monoceros were registered. They consisted of two superimposed signals - a frequency-modulated signal in the frequency range 1 - 3 kHz and a signal of frequency about 25 Hz (Bogorodsky and Lebedev, 1977, 1978). The low-frequency signal produced by a single animal was by 17 dB weaker than the corresponding high-frequency signal.

The distance from the objects of observation was about 1 km, and we can assume that, for longer distances, the relative level of the low-frequency constituent of the received signal would be higher. It was observed, that the radiation was cut off with the

appearance of a sea noise (due to the microseismic bottom vibrations in the storm zones) in the frequency range of 0.1 - 1 Hz.

Relying on the fact that the signals of frequency 20 - 25 Hz were produced simultaneously with the frequency-modulated signals, and assuming that the latter are generated by air pumping from the lungs through the system of the nasal sacks, the authors supposed that the twenty-Hertz signals arise because of the vibrations of the lungs as a pulsing spheric radiator. Simple calculations show that the resonance frequency of the lungs must be close to 25 Hz. This result allows the assumption that the lowfrequency components of the Monodon monoceros signals are epiphenomenal and do not serve for communication.

The signals of infrasound frequencies are much more important for sound communication of the mysteceti. It is well known that the frequency range of the optimum auditory sensitivity of animals usually coincides with the frequency range of the species communication signals. According to the hypothesis of the lowfrequency hearing range of the mysteceti, most of their communication signals have the spectral maxima within the range far below 1 kHz (Bel'kovich and Shchekotov, 1990). A special consideration should be given to the so-called twenty-Hertz sounds, which were first described as signals of unknown origin, but, nowadays, they are ascribed with confidence to the fin whales and blue whales.

We can assume that the signals in the frequency range 10 - 100 Hz are being radiated by all kinds of mysteceti visiting the Arctic Basin under study. But the signals produced by each of the species possess some peculiar characteristics.

A detailed consideration was given to the signals of the grey whale (Dahlheim et al, 1984) that were radiated in early spring in the Pacific waters of Mexico. Seven types of sounds were selected. The sounds of the lowest frequencies are generated during the underwater air exhaling. They consist of noise with the maximum within the range below 100 Hz. Similar signals were recorded in summer in the Chukcha Sea, which may belong to the audibility zone of the low-frequency sounds radiated in the Eastern Arctic (Petrochenko et al, 1991).

The characteristics of low-frequency tone sounds of the blue whale were studied during the visits of this animal to the St. La-



urence river; 109 records were taken during 3 - 109 min. each (Edds, 1982). Typical signals lasted 15 - 18 s. The level of the signals was increasing at the initial stage, then it was constant during 8 s, and then gradually reduced. The signal frequency was constant, being 19 - 20 Hz (Cumming and Thompson, 1971).

The signals of the fin whales are characterized by a pronounced constituent, or, even, they consist exclusively of the components in the frequency range below 50 Hz. Most of the researchers note the presence of a frequency modulation of this signal. Some data report a decrease in frequency from 22 to 18 Hz (Watkins et al, 1987) during radiation, but other show a sharper decrease: the initial frequency was 40 - 50 Hz and the terminal frequency was 10 - 15 Hz (Thompson et al, 1992). The duration of single twenty-Hertz signals of the fin whales - 0.5 - 2.0 s - was considerably smaller than that of the blue whales, and the sounds were produced in the form of series with intervals about several seconds.

The humpback whales (Thompson et al, 1986), the minke (Schevill and Watkins, 1972), and the grey whales (Cumming et al, 1968) produce narrow-band signals in the frequency range below 0.1 kHz, which consist of the first harmonics of a complex sound. Typical values of the basic frequency are close to 20 Hz.

Let us consider the intensity of the low-frequency signals of the mysteceti whales. There are no reliable data on the absolute intensity values reduced to the distance of 1 m from the source, and, hence, we will use some estimates. The sounds produced by the minke were registered in the Arctic ice region (Schevill and Watkins, 1972) by a hydrophone placed in a few meters from the animal. The narrow-band frequency-modulated signal (120 - 60 Hz) had the level of 60 - 65 dB relative to 1 dyn/cm, or, about 160 dB relative to 1 microPa. By taking into account the attenuation, we can estimate the level reduced to 1 m as 165 - 170 dB (Steward and Leatherwood in 1983, probably, did not take into account the reference point and estimated the signal as fairly weak). The level of the comparatively low-frequency (100 - 300 Hz) signal of the right whale reduced to the distance 1 m was estimated as 175 - 180 dB (Reeves and Leatherwood, 1983, Clark and Johnson, 1983).

The levels of the narrow-band signals at 20 Hz frequency are likely to be close to 170 - 180 dB. This agrees with the estimates

of the 20 Hz signal intensity of the fin whales (Payne and Webb, 1971). The levels of 20 Hz signals registered in the St. Laurence river for the blue whales were about 100 dB, but the exact distance from the animals was not measured (Edds, 1982). The registration of similar signals performed near the coast of Chile provided the 188 dB level of the total signal reduced to 1 m (Cumming and Thompson, 1971).

The incompleteness of the experimental data does not allow to consider the seasonal variations of sound radiation of the mysteceti.

### 2.2.3. Seasonal variations in species, quantity, and distribution of aquatic mammals in the Eastern Arctic

The region under consideration displays pronounced seasonal changes manifesting themselves, above all, in the change of ice conditions - decrease of ice closeness from June - July to October - mid-November and freezing of water accompanied by the increase of ice closeness in December - May. The edge of perennial drift ice moves, correspondingly, in summer - north and in winter - south.

These hydrologic processes are quite important for the whole ecosystem of the region. The annual season cycles are superimposed by the changes of weather conditions, which determine the climate fluctuations to coldness - "the ice years", or to mild years in comparison with the average indices. They determine the seasonal migrations of the settled species of aquatic mammals and, also, the possible propagation of the migrating species of aquatic mammals and whales to the regions of higher latitudes.

For normal functioning of the Arctic ecosystem, seasonal variations of biological productivity are especially important. They are caused by the hydrophysical and hydrochemical processes in connection with ice melting, freshening of the surface layer of sea water, local upwellings, and the effects of wind on the water movement. These processes cause an abrupt increase of biological production ("burst of life") during the "hydrological summer" near the polar front and in the shelf zone. This effect is an important factor determining the migration activity of numerous species of

aquatic mammals in summer - autumn period - the time of active fattening and feeding.

Because the low frequency acoustic source suppose to place northward from the line connecting the Spitsbergen island with the Franz Joseph Land archipelago, we restrict ourselves to the study of the given Arctic region. This restriction can be considered as a consequence of the estimates of radiation intensity presented in section 2.3.

In spite of all the investigations carried on for years, the data on distribution, migrations, and daily cycles of numerous pinniped and cetacean species in this region are fairly poor, fragmentary, and occasional. The pinniped, who stay in this region the whole year long, are the ringed seal and the bearded seal. They stay in water all the time except the period of shedding of hair and, partly, reproduction. The number of these two species in the given region can be estimated from many hundred to several thousand heads.

During the period from July to January, the walrus may appear over the shallow sea regions (hundreds of heads) and the harp seals (thousands of heads) may appear over the deeper sea regions. The common seal and the grey seal were not registered in this region, as well as the hooded seal, who reaches the high latitude regions to the west of Spitsbergen.

The data on the species structure, numbers, and distribution of the cetaceans are the following. Among the mysteceti, who are likely to be the most sensitive ones to low-frequency sound, the right whales (more than 100 heads) were observed in the region - in summer up to 80 deg. north and in winter near the edge of the drift ice. The fin whales are feeding in this region from April to September (more than 100 heads) and in winter they can be seen from time to time near the edge of ice (tens of heads). In summer, if there is some free water, visits of the blue whale are possible up to 80 deg. north. This species spends the winter in the temperate waters of the Atlantic Ocean. In summer, near the edge of ice, the minkes are common, but in winter most of the whales are moving south. The registered visits of the sei whale do not cross the latitude 72 deg. north, this whale appearing in the region only in summer. Slick whales may reach high latitudes, but only in

the West Arctic region; they, practically, never show up in the region near the Spitsbergen and Franz Joseph Land archipelago. In summer, a few humpback whales were seen not far from the edge of ice.

Of the odontoceti, in the region around the assumed location of the source, single sperm whales were observed in some years as well as small groups of the killer whales, and in summer and spring - small groups or pairs of the bottlenose whales. The permanent resident of the region is the monodon monoceros, whose number amounts to several thousand heads. The Beluga whales are also widely distributed over the region. Staying in the polar waters the whole year through, they concentrate in the coastal zone more often than the monodon monoceros.

The former hypothesis about the Beluga whale and monodon monoceros belonging to free water and the edge of ice regions is not completely true. Both species were registered many times far north from the edge of ice directly and in separate unfrozen water patches. Thus, at least in summer, they can be found close to the point of location of the low-frequency sound radiator.

By summarizing the results, we can see that the permanent residents of the region close to the radiation source, who can be affected by its annoying action during the whole year, are the monodon monoceros, the Beluga whale, the ringed seal, and the bearded seal. The right whale spends a considerably long time in the region. In summer, many other aquatic mammals are coming to the Eastern Arctic. In addition to the listed species, the walruses, the harp seals, the sleek whales, the fin whales and the minke whales are present in the region. On rare occasions, visits of the killer whales, sperm whales, bottlenose whales, blue whales, humpback whales, and sei whales are possible.

We should emphasise that the rare occurrence of the visits to the region of certain cetacean species being subjected presently to the anthropogenic pressure makes the system especially vulnerable. Actually, if only one or several animals will be affected, the ecological impact may be significant, though, probably, delayed.

### 2.3. Numerical simulation of spatial distribution of losses

associated with low-frequency sound propagation in Arctic

Numerical simulation of low-frequency sound propagation in the Arctic region under consideration is accompanied by a number of difficulties. The first one is the absence of reliable and detailed data required for formation of a mathematical model of a hydroacoustic waveguide.

Because of the geographic location of the radiation source (lat. = 82,5 deg. North, lon. = 30 deg. East) near the Arctic continental slope, the quality of bathymetric information becomes significant. It is especially important for simulation of sound propagation in the Southern direction when the propagation paths cross the continental slope and come to the shallow waters surrounding the Spitsbergen and Franz Joseph Land archipelagos and being the outskirts of the Barents Sea shelf. In the Northern direction, the depth variations are much smaller. The thickness of the water layer is about 4 km, and only at distances exceeding 300 km, where the propagation paths cross the Sedov ridge, the depth may decrease to 3 km. We used the bathymetric information from the map scaled 1 : 15000000 from the atlas of the Arctic Ocean. The map providing the bathymetric information is presented in Fig. 1. The isobaths show the depths 3000 m, 2000 m, 1000 m, 500 m, 200 m, and 100 m. This map and the following patterns are constructed in the azimuth normal equigraphic (Lambert's) projection with the point of contact at the North Pole.

The simulation of the distribution of sound velocity along the propagation paths was made in the following assumptions. The vertical sound velocity distributions  $C(Z)$  in the deep-water and shelf water areas of the region under consideration were assumed to be distance independent. The profile  $C(Z)$  for a deep-water area is shown in fig. 2. It corresponds with the typical surface sound channel of the Arctic Ocean. The vertical distribution  $C(Z)$  on the shelf is shown in Fig. 3. It is characterized by a clearly defined antichannel, whose axis is situated at the depth 200 m. The transition from the deep-water distribution  $C(Z)$  to the shallowwater one is performed between the 1000 m and 500 m isobaths by linear interpolation.

One of the most complicated problems is the problem of acous-

tical characteristics of the hydroacoustic waveguide boundaries. The low radiation frequency of 20 Hz requires the knowledge of the acoustical characteristics of the sea bottom down to the depths about several hundred meters. Above all, this is important for simulation of the sound fields on the shelf, where the sound attenuation of such a low frequency will be governed by the reflectivity of the sea bottom. Because of the lack of sufficient and reliable data on the structure of the bottom deposits, we used for the entire region the most simple model of sea bottom in the form of a liquid half-space of density 2000 kg/m and sound velocity  $1.65 \cdot (1 - 0.005i)$  km/h.

An important feature of the sound propagation channel in Arctic is the presence of the ice cover, whose simulation is difficult because of its spatial and time variability. However, this fact does not hinder the sound field calculations, because, at 20 Hz frequency, the influence of ice on the sound field appears to be insignificant. For example, if the ice is simulated by a uniform elastic plate characterized by the parameters: thickness 5 m, density 900 kg/m, longitudinal wave velocity  $3.5 \cdot (1 - 0.03i)$  km/s, transverse wave velocity  $1.7 \cdot (1 - 0.1i)$  km/s, calculations of the sound field in the deep water showed that the presence of ice leads to attenuation of sound level at 500 km distance only by 2.5 dB compared to the case of a perfectly soft upper boundary. This is explained by the fact that, at such frequency, the sound reflection coefficient from ice is close to unity for all grazing angles. The scattering properties of ice at 20 Hz frequency also have no marked effect on the sound level (Gavrilov et al, 1993). Hence, we believe that there is no sense for us to consider the effect of seasonal changes of the ice cover on the sound field, since the information we use for our calculations on all other parameters of the waveguide is fairly rough. Besides, the study carried out by Numrich (Numrich, 1978) proved that the influence of the vertical sound velocity distribution on the sound level, even at such low frequencies, is much stronger than the influence of the ice cover.

In parallel with the construction of a mathematical model of the hydroacoustic waveguide, there is an important problem of choice of the sound field calculation method. We believe that the

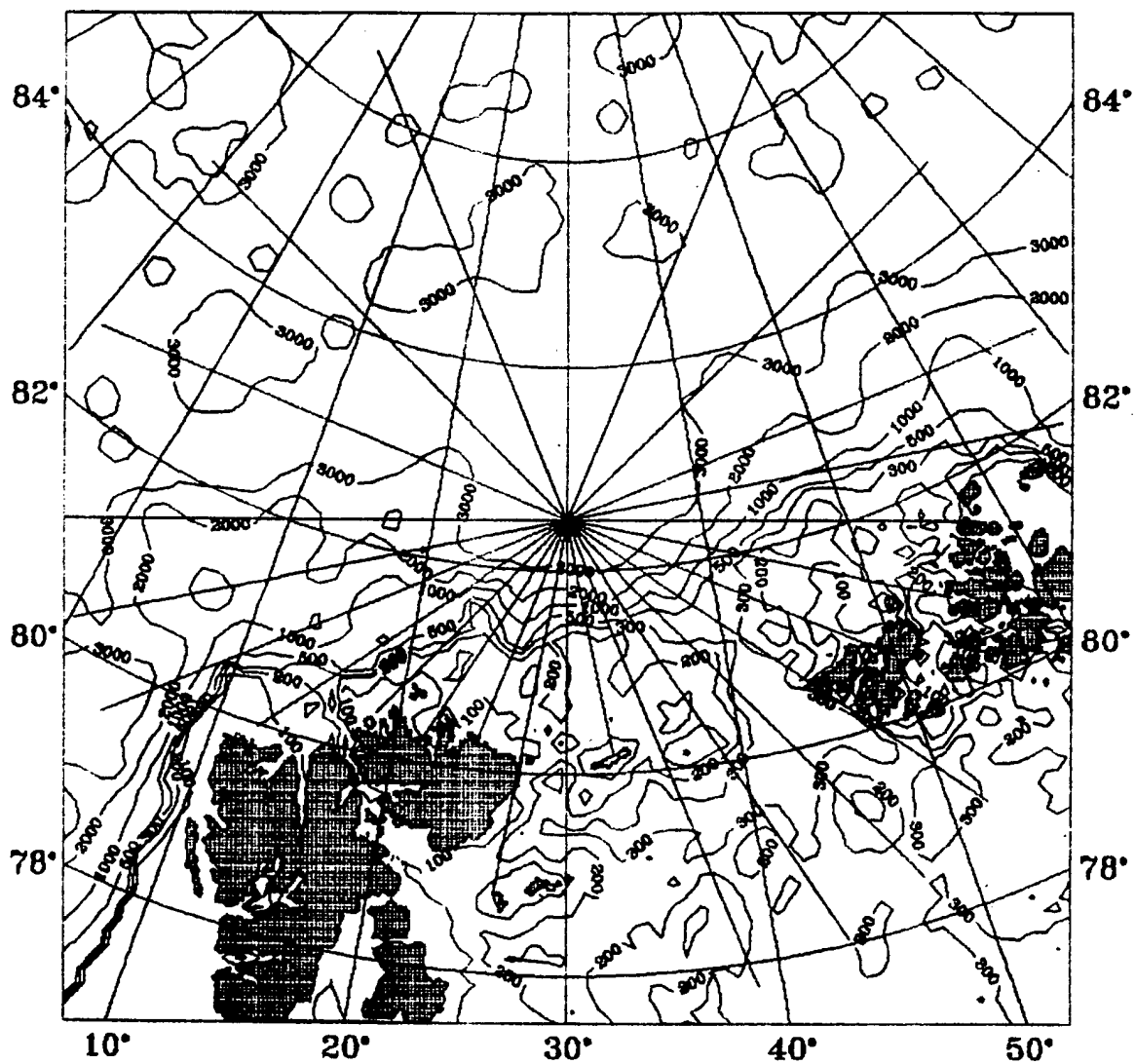
method of transverse sections (Brekhovskikh and Lysanov, 1982), which enables us to take into account the presence of the ice cover and possible elastic properties of the sea bottom, is the best suited method for simulation of low-frequency sound fields in Arctic. Because of the significant spatial variability of the characteristics of the propagation channel and, above all, the depth changes in the continental slope region, strictly speaking, we should take into account the interaction between the modes. But, since in the deep-water part of the waveguide the major portion of energy is concentrated in the surface sound channel, the spatial change of the effective waveguide thickness is considerably smaller than the depth change. Hence, we decided to perform all our calculations in the framework of adiabatic approach of the method of transverse sections.

The losses associated with sound propagation were calculated for the depth of radiation being 20 m, along a variety of paths in different directions; the angles between different north-directed paths were 22.5 deg., and between different south-directed paths they were 11 deg. 15 min. The disposition of the paths is shown in Fig. 1. The maximum distance from the source was 550 km. The calculations were done using the energy summation of the modes, which correlates with local averaging of the sound field over the distance.

The patterns of spatial distribution of losses accompanying the sound propagation at the depths 25 m, 50 m, 100 m, 200 m, 400 m, and 800 m are shown in Figs. 4 - 9, respectively. The lines of equal loss values are plotted in the interval from 60 dB to 120 dB with the step 2 dB. The patterns were constructed by interpolating the calculated values of propagation losses to an equidistant spatial grid, the values taken in its nodes used for calculation of the positions of the lines of equal sound field levels.

We can see that the structure of the sound field in the deep-water part of the region under consideration depends not too strongly on the propagation direction. Here, the value of losses during the propagation is determined by the depth of reception. In particular, the minimum values of propagation losses at a given distance correspond to the depth of 100 m, and the maximum values - to the depth of 25 m. Such distribution of the sound field level

Arctic Zone.  
Source location: 82°30'N 30°00'E.



SCALE 1 cm. = 75 km

Fig.1. Bathymetric map and location of acoustic paths.



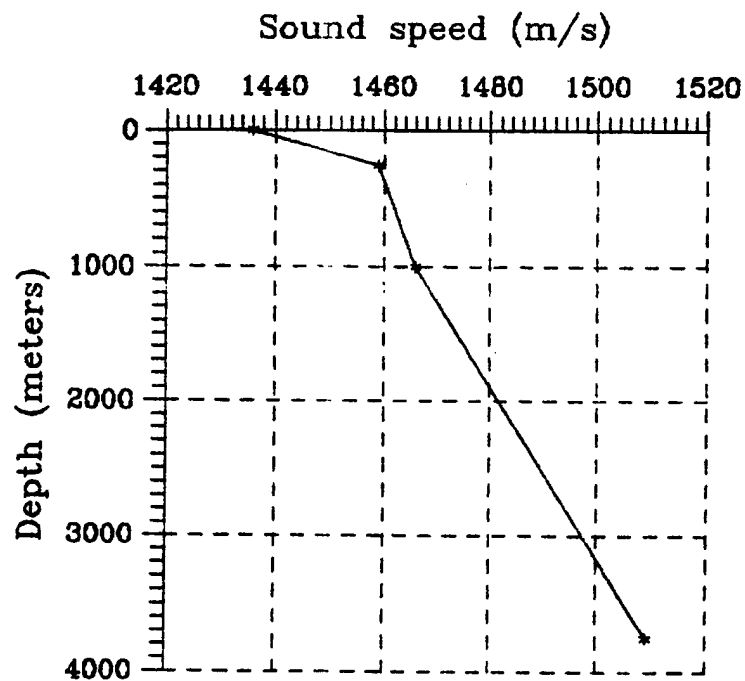


Fig.2. Sound speed profile for deep sea area.

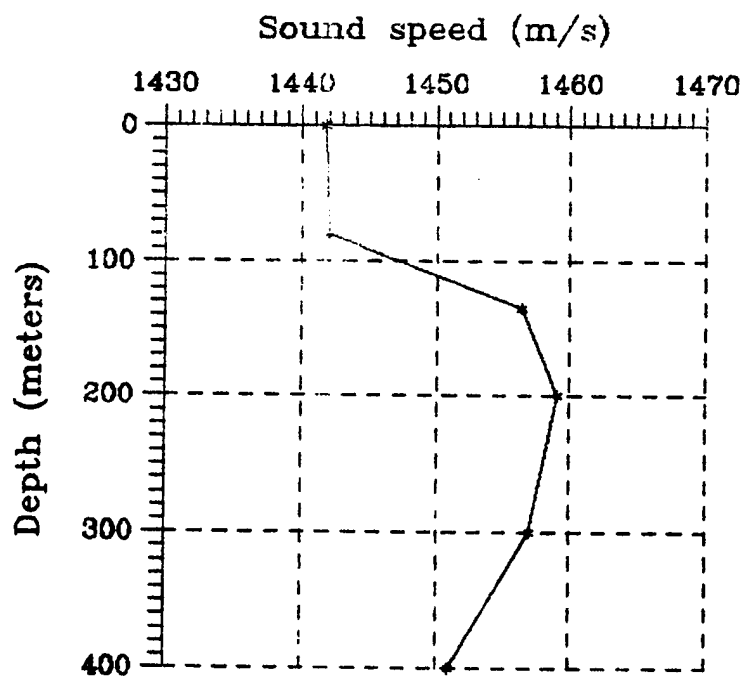


Fig.3. Sound speed profile for shelf area.

Arctic Zone.  
Source location: 82°30'N 30°00'E.  
Source depth = 20 meters, Frequency = 20 Hz.

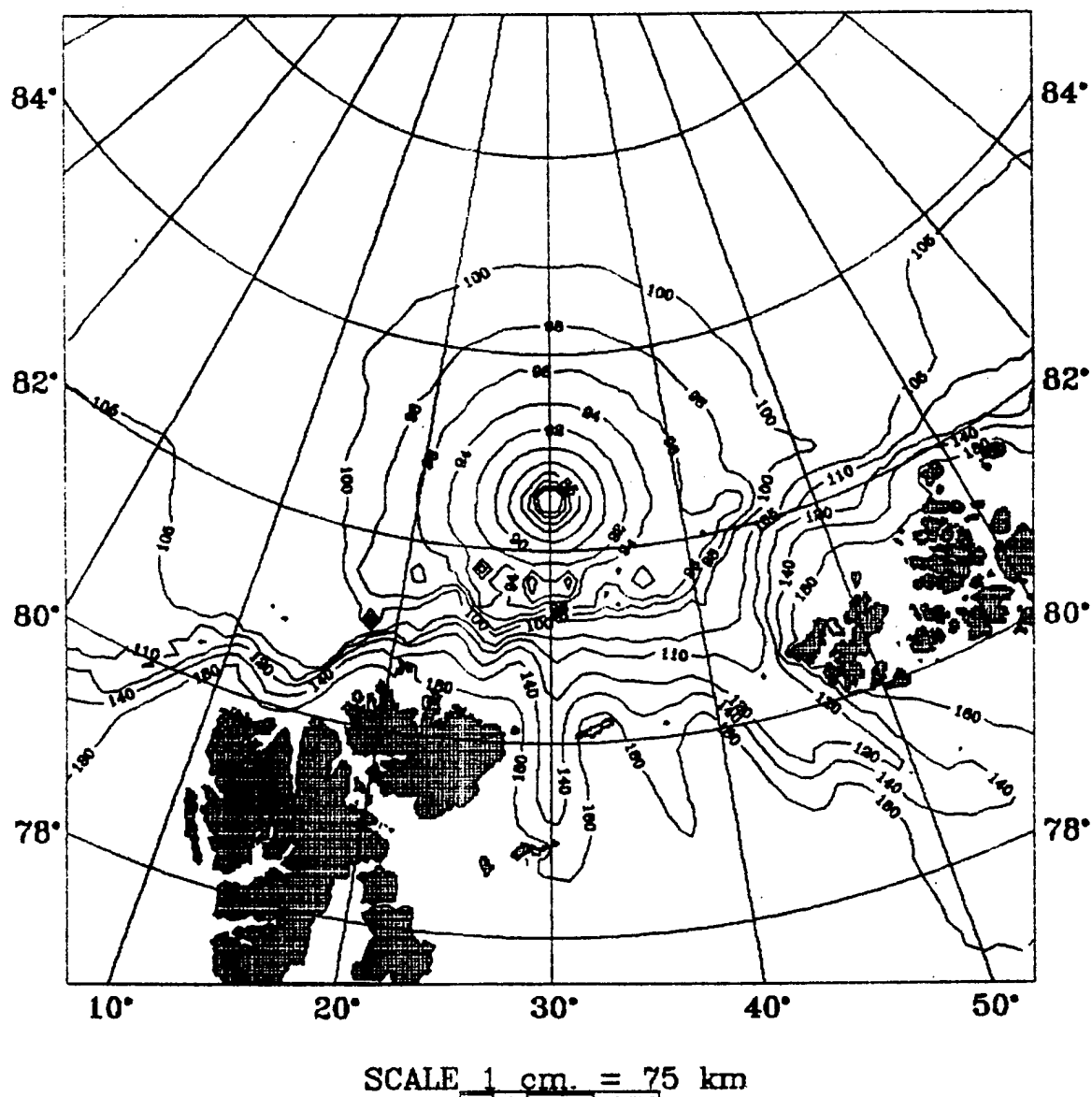
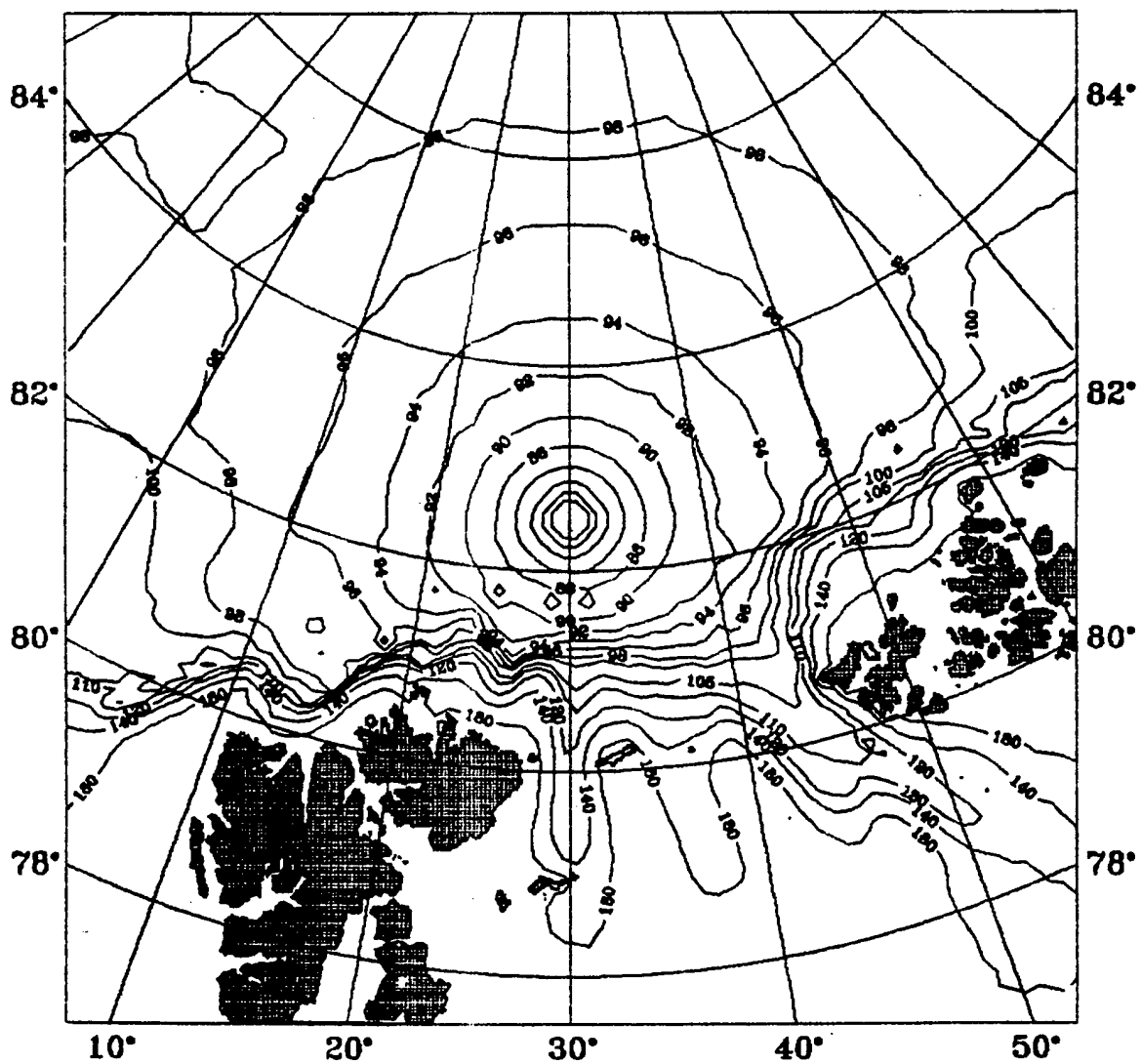


Fig.4. Transmission Loss at 25-m depth.

Arctic Zone.  
Source location: 82°30'N 30°00'E.  
Source depth = 20 meters, Frequency = 20 Hz.



SCALE 1 cm. = 75 km

Fig.5. Transmission Loss at 50-m depth.

Arctic Zone.  
Source location: 82°30'N 30°00'E.  
Source depth = 20 meters, Frequency = 20 Hz.

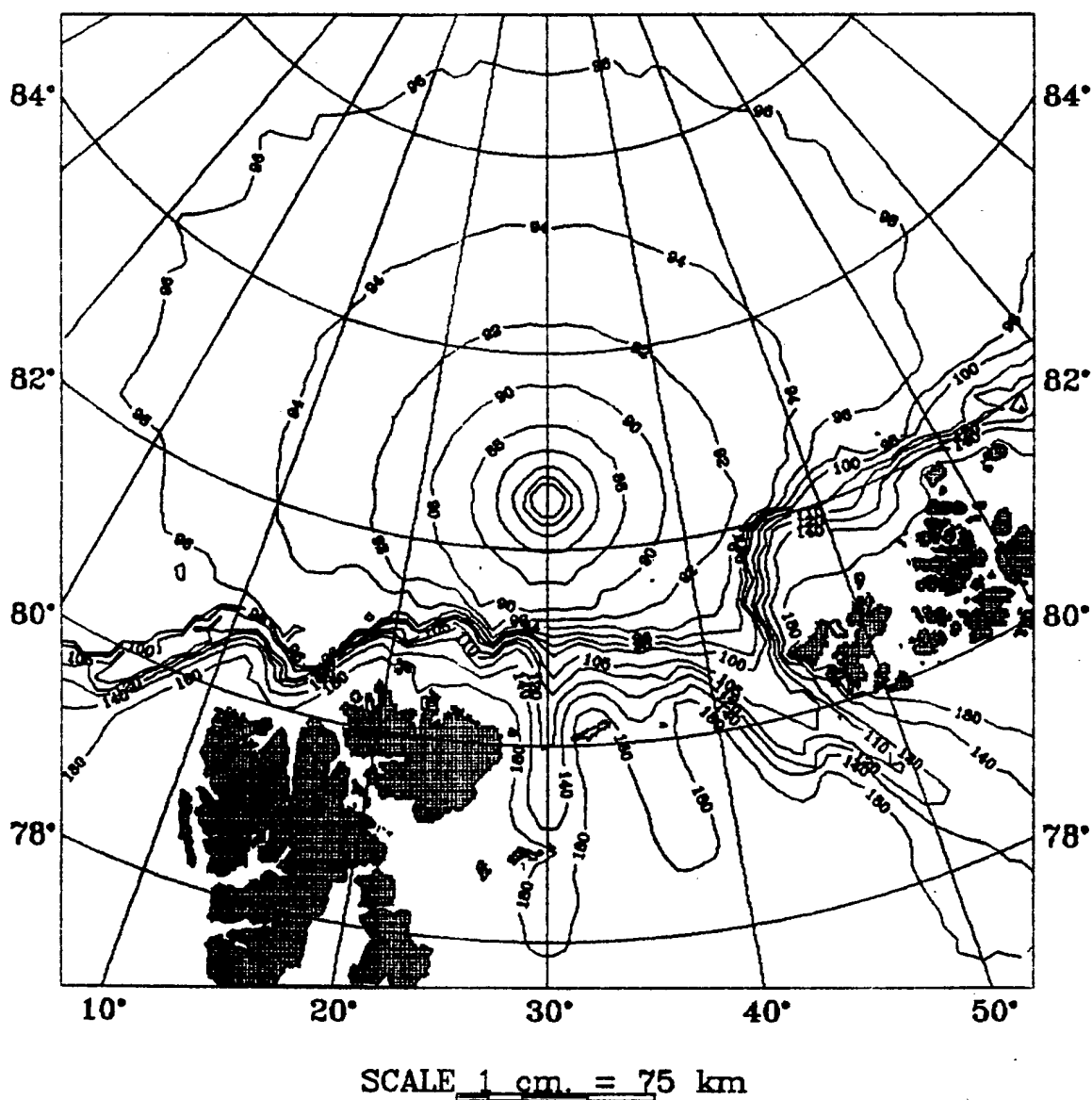


Fig.6. Transmission Loss at 100-m depth.

Arctic Zone.  
Source location: 82°30'N 30°00'E.  
Source depth = 20 meters, Frequency = 20 Hz.

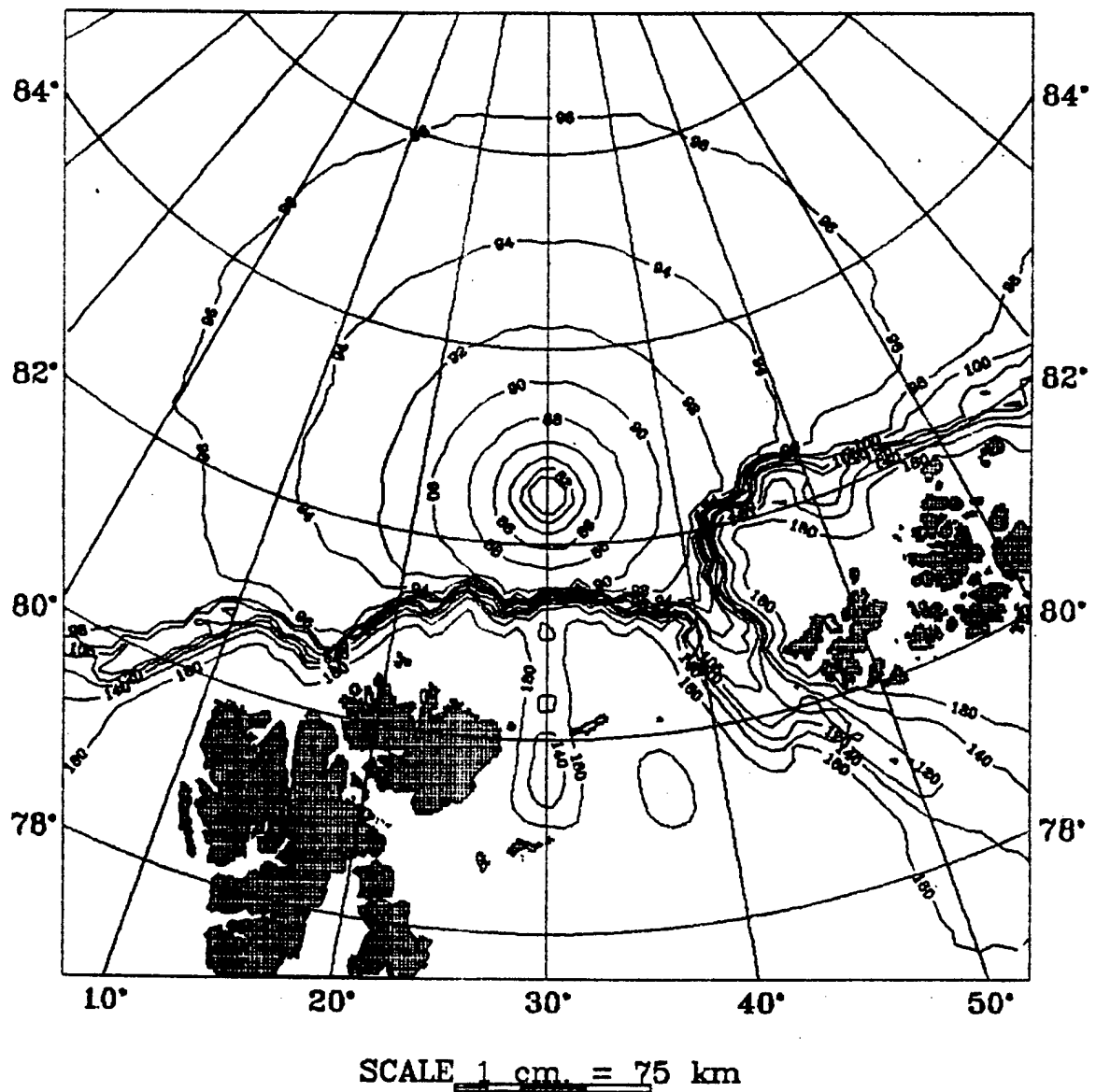
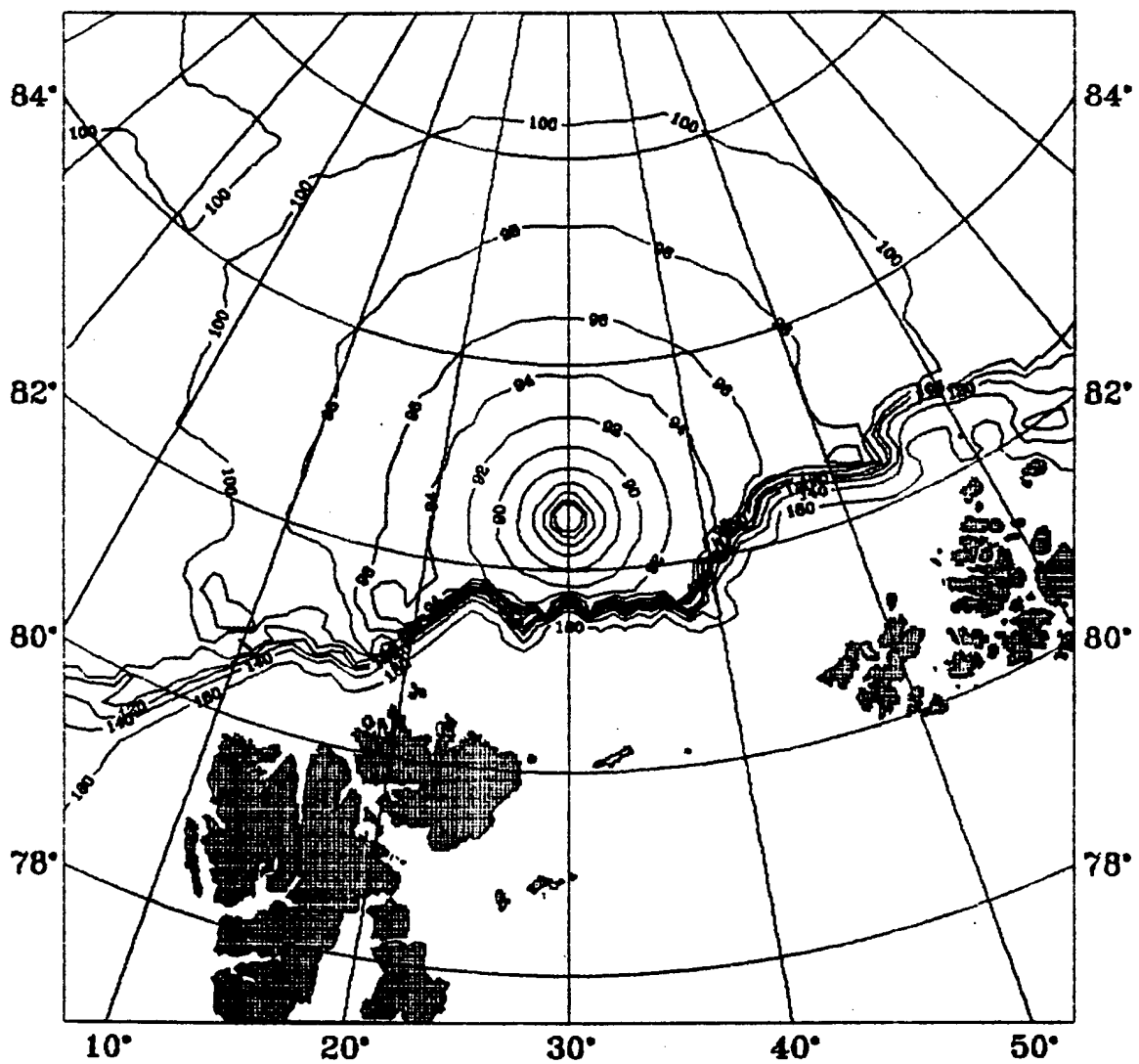


Fig.7. Transmission Loss at 200-m depth.

Arctic Zone.  
Source location: 82°30'N 30°00'E.  
Source depth = 20 meters, Frequency = 20 Hz.



SCALE 1 cm. = 75 km

Fig.8. Transmission Loss at 400-m depth.

Arctic Zone.  
Source location: 82°30'N 30°00'E.  
Source depth = 20 meters, Frequency = 20 Hz.

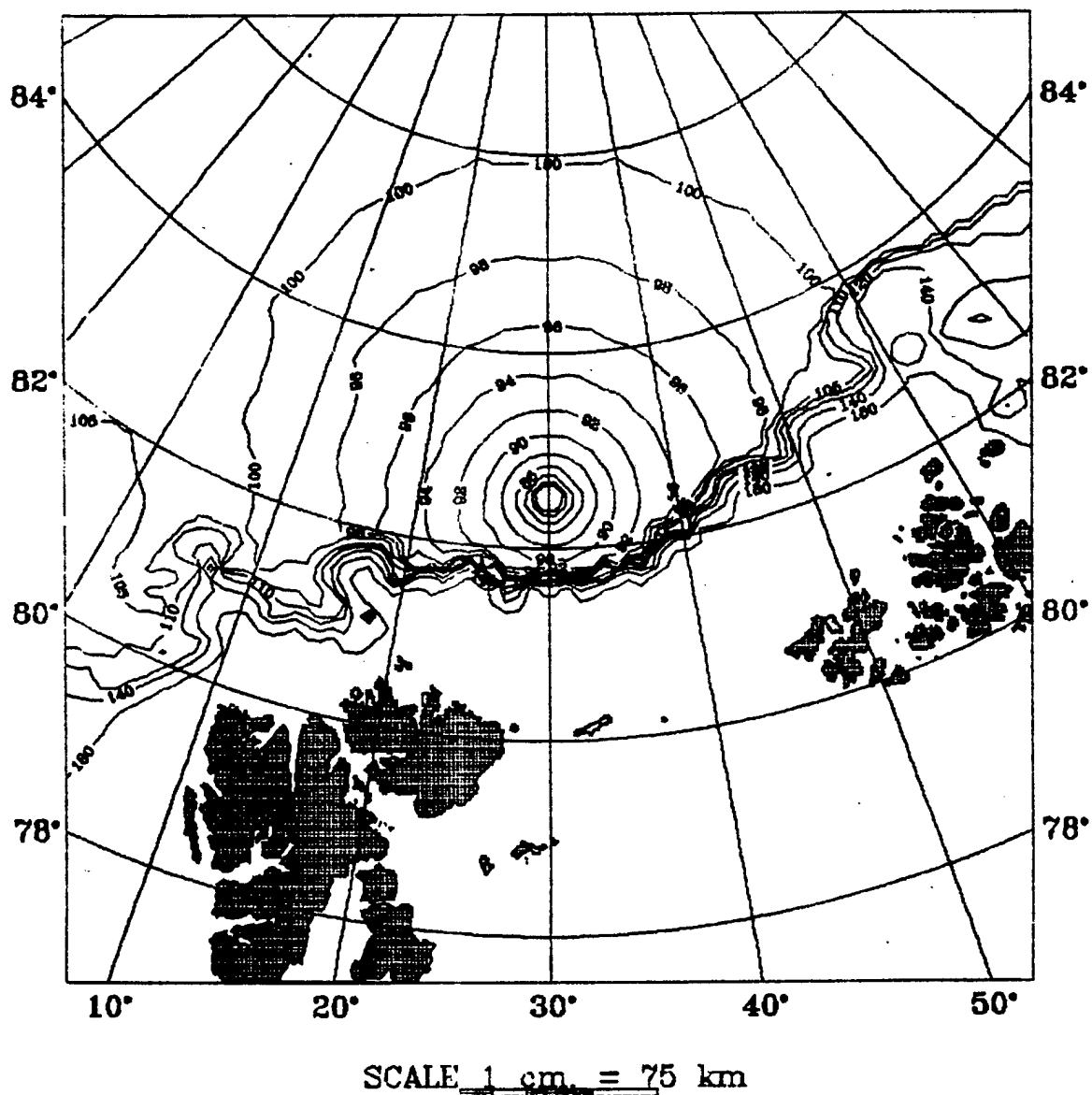


Fig.9. Transmission Loss at 800-m depth.

in depth is explained by the presence of a surface sound channel in the vertical distribution of sound velocity  $C(Z)$  and sufficiently low radiation frequency. The influence of the sea bottom relief in this part of the region is insignificant because of the large depth values. We may note a small decrease in the loss values for propagation in the north-west direction related to the focusing effect of the smooth decrease of the width of the propagation channel near the coast of Greenland.

A much more complicated spatial structure of the sound field can be seen for the west, south, and east directions. The presence of the continental slope, large areas of shallow water, and coastal line leads to the anisotropy of the spatial distribution of the values of propagation losses.

To the west, at the inlet of the Greenland Sea, there is a bottom rise Ermak characterized by the local depth about 600 m. This rise is blocking the signal propagation, which causes a considerable loss increase in this direction. Because of this, in case of the given location of the radiator, the sound signals can get to the Greenland Sea only through a sufficiently narrow Litcke gorge between the Ermak rise and Spitsbergen archipelago.

The sound propagation to the Barents Sea is hindered by the archipelagos Spitsbergen and Franz Joseph Land and by the adjacent shallow waters. It is only in the south-east direction along the Franz-Victoria trough that part of the sound signals can penetrate to the Barents Sea, these signals being considerably weakened. At the outlet of the trough, the value of propagation losses is by 10 - 15 dB higher than the one for the north direction at the same distance from the source.

In conclusion, we note that the obtained results should be regarded as preliminary, because of the fairly rough initial data. To obtain more reliable estimates, one should refine the acoustic waveguide model, and, above all, the acoustic characteristics of the bottom deposits on the continental slope and in the shelf region.

2.4. Estimates of potential effects of low-frequency narrow-band radiation on marine mammals of the Arctic Basin



In this section, we consider the possible ecological effects of the powerful underwater low-frequency acoustic radiation. The assumed signal parameters are: the central frequency - 20 - 30 Hz, the band width - from several Hz to several tens of Hz, duration - several tens of minutes, the sound level relatively 1 m range from the source - about 200 dB relative to 1 microPa. Our main concern is the possible influence of these effects on vital activity of marine mammals of the Arctic Basin. We differentiate the following aspects of possible acoustic influence: informational, annoying, injuring, and influence on some other organisms that potentially can affect the vital activity of marine mammals.

#### 2.4.1. Potential informational effects of low-frequency acoustic radiation.

Any ambient sound received by living organisms is able to cause some changes in their behaviour that may be undesirable.

As we can conclude from the analysis of the data on auditory sensitivity and auditory communication of marine mammals (section 2.1 and 2.2) and from the characteristics of sound propagation in the region under study (section 2.3), the animals most likely affected by low-frequency radiation are the mysteceti. The low-frequency (20 - 30 Hz) signals, presumably, will be received by them over a wide water area, covering an area of mysteceti dwelling. For the odontoceti and the pinniped, it is most probable that their zone of audibility will be restricted to the region, where the signal level exceeds the value of 150 dB, that is, within several kilometers from the sourcer.

Consequently, to determine possible negative informational effects of the acoustic thermometry source, we have to reveal the functional informative role of low-frequency narrow-band signals of the mysteceti. Our knowledge in this field is obviously insufficient. All our speculations on the long-range communication, fish deafening, and the like, stay without proper support because of the lack of complete experimental studies.

However, we can say that the most probable function of these sounds is the informational long-range communication between indi-

vidual whales. A few experiments demonstrated the effect of attraction of intraspecific sound signals. Well-defined response was observed by studying the behaviour of one of the southern sleek whales, who approached the source three times - always, when the intraspecific signal was radiated, and ignored the source, even moving away from it, under the radiation of any other sounds (Clark and Clark, 1980). For the humpback whale, the attracting effect of a reproduced communication signal was also observed (Helweg et al, 1993). Reproduction of the sound produced by a feeding female whale proved to be the most efficient in these experiments. Thus, the data available suggest that the low-frequency signals serve for communication between widely separated odontoceti. This statement may be supported indirectly by the recent discovery of infrasound communication between the largest of the land mammals - african elephants - over the distances of dozens of kilometers (Langbauer et al, 1991).

In some cases, signals of an artificial origin could be attractive for the whales, as well. For example, a case was described, when the grey whales deliberately approached a source of low-frequency noise represented by an idling vessel (Dahlheim et al, 1981).

On the basis of the data given above, we can not exclude a possibility that low-frequency signals may lure the animals under the ice cover. The researchers registered many times the whales diving and swimming under a solid ice cover in searching for food (Richardson et al, 1987). It is also known that these animals are able to detect the zones of thin ice cover and to emerge at the surface hundreds of kilometers away from the edge of ice. It is obvious that in such cases they need to orient themselves perfectly under the sea surface. The role of sound signalling and sounding in this process is yet unclear.

In any case, there is no doubt that urgent experimental studies must be carried out in order to reveal the informational function of the signals of mysteceti in the frequency range below 100 Hz and to study their response to such stimuli. The lowfrequency source would be highly useful for these purposes at the stage of stationary path testing for the system of the "Acoustical Thermometry of the Ocean Climate" (ATOC).

#### 2.4.2. Potential disturbance and annoyance effects caused by lowfrequency sound radiation.

We fully agree with the experts (Low frequency ..., 1994), who reason that sound signals received by marine mammals by ear can not be considered a priori as harmful and causing annoyance or disturbance in animals. But we should notice that the audiometric curve of most of the land mammals and their frequency dependence of sounds, which cause annoyance or pain, merge at the edges of their audible frequency range. If we extend this data to the case of marine mammals, we can assume that, in the frequency range 10 - 100 Hz, the thresholds of annoyance of the odontoceti and pinniped are only by 15 - 20 dB higher than their thresholds of audibility, this difference decreasing with the decrease in frequency. With such speculations we can estimate the annoyance threshold for these whales at frequencies about 20 Hz as 160 - 165 dB.

However, we should emphasise that numerous dolphins enjoy sliding over the navigation-produced waves in the zone, where the low-frequency noise levels are well over 170 dB.

In the case of the mysteceti, the assumption about the audibility and annoyance thresholds coming closer at low sound frequencies may be wrong. If we do not exclude tuning of the basilar membrane of these animals to the sounds of the range 10 - 100 Hz (Ketten, 1993), then the interval between the audibility threshold and threshold of annoyance can exceed 60 dB. Such mental conclusion agrees with the data of the studies aimed at determination of the low-frequency signal levels, which would cause a negative response of the mysteceti whales, these studies being performed in relation with ecological security of seismic prospecting and mining.

The studies of possible effects of pneumatic pulse source used for seismic prospecting on the behaviour of the right whales were carried out during the summer seasons of 1980 - 1984 in the Bophort Sea (Richardson et al, 1986). Both single pneumatic guns and a fully equipped vessel with a set of guns for seismic prospecting were used. The signals consisted of pulses of no less than 0.5 s duration having a pronounced spectral maximum within 50 - 80

Hz. Under the signal levels below 160 dB, only small changes in the behaviour of the animals were registered. They involved, mainly, small (but statistically significant) decrease of diving durations. When the seismic prospecting vessel approached the whales to the distance of 3 km, most of the 6 whales under study moved away from the source of sound. The response was not sharp, and the speed of the whale's movement was characterized as slow to intermediate. The signal level during this period of time was well above 160 dB.

Similar detailed studies were performed on humpback whales in summer 1984 near the south-east coast of Alaska (Malme et al, 1985). The stimuli used in this study were signals from pneumatic guns and records of signals from oil pumping equipment under operation (vessels, submerged and half-submerged platforms). The feeding whales were observed from two boats using triangulation methods for localisation of the whales. The basic criterion in estimation of the behaviour of the animals was the time they spent at the surface and the direction of their movement. The maximum signal intensities were 172 dB for the pneumatic source and 116 dB for continuous signals of the boring machines. Although, under the radiation, the distance between the source and the whales was increasing in many cases of observation, the reference measurements showed the same tendency in the absence of signals. Presumably, the effect originated from the fact that, during the initial stage of work, the vessel was fairly close to the whales, and simple random movements could bring them away from the source. Thus, no annoying or disturbing effects of noise were found in this study.

More evidence for the annoying effect of loud low-frequency noise was obtained by observing migrating grey whales near the coast of California (Malme et al, 1983, 1984). For these experiments, records of various boring machines and a pneumatic gun (of 100 cubic inches volume and 4500 pounds per square inch working pressure) were used as a source of sound. The disturbing effect of noise was evaluated by tracing the whales movement and the estimates of the deflections from the trace. The effect of avoiding the pneumatic gun signal was reliably established for 10% of whales at 164 dB noise level, for 50% of whales at 170 dB noise level, and for 90% whales at 180 dB noise level. Taking into account that the

deflections were not too large and did not violate the general migration picture, we can say that the real annoying effect is produced only by the signals, whose level exceeds 175 - 180 dB. The given values refer to the energy averaged over the pneumatic gun pulse duration. It is obvious that continuous signals can cause annoyance at considerably lower levels. The same authors observed the effects of avoiding on 50% whales subjected to continuous action of reradiated signals of boring machines at a level about 117 - 123 dB depending on the machine type.

A detailed study of the grey and right whales response to the sounds of real operating boring machines in the Bophort Sea lead to a conclusion that the noise effect should be measured, instead of the absolute noise level, by the excess value of the noise level under study over the level of the sea noise. The estimate of the excess signal over the sea noise, that caused the effect of avoiding in 50% of animals, provided the level of 30 dB (Miles et al, 1986, 1987). But, in this case, the responses were also not too sharp, and, probably, were related to the uncommonness of the noise. The experiments in the pool (on Beluga whales) showed that, at the moment the sound reproducing the noise of a boring machine was turned on, the animal demonstrated a sharp avoiding response, but, after a while, it relaxed and could swim easily in the immediate vicinity of the source, where the level was at least 153 dB (Awbrey et al, 1986, cited from Malme et al, 1989).

The main interest is attracted to the preliminary data characterizing the behaviour of marine mammals during the experiment on acoustical thermometry in the Tasmania Sea (Bowles et al, 1992). This data can be considered as nothing but preliminary. The authors registered no sharp changes in the behaviour of the animals close to the ship radiating the signal of frequency band - 30 Hz and centered at frequency 57 Hz. But the absence of any registered communication signals of the whales during radiation should give one some concern. The behaviour of one of the whales, who followed the source over 11 km long, may also be a warning. As it was mentioned above, the potential effect of attraction of low-frequency signals in the polar region may be a problem.

#### 2.4.3. Potential injury to marine mammals that can be caused

by low-frequency sound radiation.

It is common knowledge that injuring effects of intensive sound signals consists, mainly, in upsetting the normal functioning of external hair cells, which perform the active frequency discriminative amplification of the weak mechanical vibrations of the cochlea. Such deteriorations lead to irreversible rise of the absolute thresholds of audibility and to the depression of the frequency discrimination (Davis, 1983). Numerical data on such effects in marine mammals were obtained only for the bottlenose dolphin in the high-frequency range (Ridgway and Carder, 1993). Although, the deteriorating effect of low-frequency radiation on hair cells is usually considered as comparatively small, this approach may be invalid for the mysteceti because of the distinctive features of their internal ear construction - above all, the small thickness and considerable width of their basilar membrane (Ketten, 1993). We should also take into account some of the recent observations demonstrating serious injuries of the auditory system of the mysteceti - those, who happened to approach the sites of underwater explosions. In this connection, we should note that the signal levels causing these injuries were by several orders higher than the levels intended to be used in the source under investigation.

The direct action of the intense low-frequency sound and infrasound on such organs as heart, liver, and lungs must be also considered. A calculation of the resonance characteristics of a lung as an air bubble in the water medium was performed for the monodon monoceros (Bogorodsky and Lebedev, 1978). The obtained estimate - 26 Hz, falls within the range of the central frequencies of the "ATOC" system radiation. Animals with smaller lung volumes have higher resonance frequencies, and the mysteceti have significantly lower resonance frequencies. However, according to the results obtained from the studies of the effect of infrasound in air, direct action on the somatic organs of large animals takes place at levels well above 200 dB.

Our estimates of the lowest sound intensities in the 10 - 100 Hz frequency range, that can injure marine mammals, are purely speculative. To a first approximation, these levels are 180 - 200

dB and can be observed only in the immediate vicinity of the radiator.

While predicting possible injuring effects of radiation on marine mammals, we should take into account the fact that the animals can leave the zone of risk by themselves. Hence, we recommend to begin the radiation with an intensity much lower than the maximum one.

2.4.4. Potential effects of low-frequency sound radiation on the marine animals, which are a factor of the vital activity of marine mammals.

The vital activity of marine mammals is affected, above all, by the organisms, which constitute their food. The food of the odontoceti whales and pinniped consists mainly of fish, and the mysteceti prefer small-sized crustacea.

The effects of low-frequency sound on fish can also be divided into informational, annoying, and injuring effects. The absolute thresholds of audibility of fish in the infrasound range are very low. Thresholds determined by the violation of cordial rhythm in cod were similar to those in amphibian, their sensitivity being thousand times as high as the vibrational sensitivity in humans (Sand and Karlsen, 1986). Consequently, the infrasound audibility of fish, like that of the mysteceti, seems to be determined by the level of sea noise, rather than by the absolute sensitivity. We should note that fish, opposite to the odontoceti and land mammals, are characterized, at frequencies below 100 Hz, by a monotone decrease of the critical ratio with the decrease of frequency (Hawkins and Chapman, 1975). A numerous fish radiate signals of low audio and infrasound frequencies. Fish are also able to determine the direction toward the source of lowfrequency sound in the far field both in the horizontal (Buwalda et al, 1983) and vertical (Hawkins and Sand, 1977) planes. The above mentioned studies were carried out on cod - one of the most important fishery species of the Arctic Basin. Hence, the problem of possible influence of low-frequency radiation on the paths of migration of arctic fish calls for further investigation.

The informational and annoying effects of sound on the inver-

tebrates was never studied. But, there are some data indicative of the existence of sufficiently sensible mechanical receptors in cephalopodan and mollusca (Budelman and Bleckman, 1988).

All studies of the injuring effects of intense sound on various marine animals were usually done in application to the pulse signals from pneumatic sources used for seismic prospecting. It was shown that the probability of a lethal effect on fish depends on the size of the fish body. The allowable limiting power of the pulse signal is related with the linear size of fish by a power dependence, which holds in the size range from millimeters to several meters (Hill, 1978).

Under the radiation produced by pneumatic radiators of working volume up to 10 liters, the radius of lethal effect on food-fish of the Arctic Basin (cod, plaice) was about 1 m, and the radius of heavy injure - about 2 m. At distances more than 3 m away from the source, no visible changes were registered. The worst kind of injures, which was seen mostly in fish larvae, consisted in retina exfoliation revealed by microscopic studies (Muraveyko et al, 1992). Larvae with such defects will have seriously deteriorated vision are likely to stay blind. It should be noted that the larvae can not leave the intensely affected zone as easy as adult fish. But, the presence of larvae in the immediate vicinity of the radiator, where such dangerous radiation levels can exist, is fairly improbable.

Possible effects of intense sound on the auditory system of fish and some other marine animals are yet unknown, though this system is likely to be the most vulnerable. Currently, we are developing a testing object, which could help to evaluate the state of the auditory system of aquatic and half-aquatic animals both under the normal conditions and after being subjected to intense underwater sound radiation (Bibikov and Elepfandt, 1993).

In addition to the effects on the sensorial systems, we should be concerned about the possible resonance effect of intense narrowband low-frequency radiation on the swimming-bladder of large-size fish. There may be also some effect on the survival of the sprawn (Kostyuchenko, 1973).

Visible changes in small-size invertebrates after intense radiation from pneumatic guns were minimal (Muraveyko et al, 1992).



Even 1 m away from the source, they remained practically unaffected. But we should take into account, firstly, the possible effects on the primitive mechanical receptor systems and, secondly, the possible delayed effects. Some of the effects were observed in the experimental studies of growth and development of Crandon crandon. In a pool, under an elevated by 20 dB noise level reaching its maximum at the frequency of 50 Hz, the animals development slowed down, the death-rate increased, and the behaviour became more aggressive, which manifested itself in the form of cannibalism (Lagardere, 1982).

2.4.5. Influence of specific low-frequency radiation parameters on the vital activity of marine mammals of the Arctic Basin.

#### Intensity

On the assumption of the radiation mode: 30 min of continuous radiation repeated periodically every 4 h, we can estimate the effects of the radiation intensity as follows:

1. under the sound levels over 180 dB, the auditory systems of marine mammals and fish may be deteriorated, and, for small-size fish and larvae, deterioration of organs of vision and partial lethality is possible (within the radius of several meters from the radiator);
2. under the sound levels over 150 dB, annoying effect of radiation is possible affecting all marine mammals and fish, along with some negative influence on the vital activity of small-size crustacea (distance from the source - up to 1 - 2 km);
3. at signal levels exceeding the sea noise level in the one-third-octave band centered at the source frequency, the radiated signals can be received by the mysteceti and fish (distance from the source - depending on the conditions of sound propagation, up to 1000 km).

#### Duration

When evaluating potential negative informational effects of radiation on the mysteceti whales, we should consider two possible risks: the attracting effect of the signal and violation of acoustic communication. The effect of attraction may result in undesirable visits of the animals under the ice cover. The data availab-

le concerning the whales ability to find the thin ice regions, although they are quite convincing, need further experimental verification. On the other hand, the violation of acoustic communication between the objects may cause desynchronization in the behaviour of the objects and result in shoal scattering. According to the behavioural data, the speed of the mysteceti movement caused by the radiated sound signals must not exceed 6 knote. Thus, during the time period of 30 min, the animal moving under the action of sound can cover a distance of only 5 km. On the assumption of the long-range acoustic communication, such travels are not likely to cause any shoal scattering.

We should emphasise marked differences between the time parameters of signals of an artificial origin and the sounds of species communication. In this connection, a continuous 30-min radiation seems to be more preferable than pulsed radiation, which may resemble the sounds produced by the fin whales or blue whales.

When evaluating potential annoying and deteriorating effects, we should consider that the marine mammals and large-size fish can be quite active to leave the zone of risks. To realize this possibility, one should start the radiation with a comparatively low intensity level, and increase it gradually according to a logarithmic dependence (linear in the dB scale) up to the maximum intensity. The time period, which is required for such increase in amplitude, may be 3 - 8 min.

The effect on immobile objects will be determined by the total radiation time. Hence, after the initial stage of the system operation, when the intervals between the radiation periods are 4 h, it would be desirable to increase the mark-space ratio by producing signals with a period of 8 - 12 hours.

#### Radiation frequency

The 20 Hz frequency represents some potential risk related to possible interference to the exchange of information between the large-size mysteceti. In particular, despite the marked distinctions in its temporal structure, the artificial signal can be received and accepted as a species communication signal. In this connection, possible ways to change the radiation frequency to 30 Hz or to 15 Hz should be studied. On the other hand, we should note, that the presence of a pseudo-random frequency modulation in the

source of the "ATOC" system makes it quite different from the communication sounds, which consist of either a mono-frequency signal (blue whale) or a signal with linear frequency modulation (fin whale), or a signal including a set of harmonics (minke, right whale). Actually, the sounds produced by the "ATOC" system most closely resemble the natural low-frequency sea noise due to seismic and hydroseismic phenomena. It is obvious that, on the assumption of sufficiently high development of the low-frequency hearing of mysteceti, we can consider them to be able to discriminate easily between these sounds and the communication signals. But to exclude all the risks, the behaviour of the whales should be carefully observed at the stage of system's operation testing.

### 3. Conclusions.

1. The analysis of the literature demonstrates a severe deficit of experimental data on the influence of low-frequency radiation on the ecological system of the Eastern Arctic as a whole and, specifically, on marine mammals.

2. To perform preliminary estimation of possible influence of the radiation, we have used indirect data, which characterized the species structure, the auditory sensitivity, the parameters of auditory communication, and also the responses of the animals on intense sound radiation in other regions of the Ocean.

3. The data on the species structure and seasonal changes testify to the high vulnerability of the Arctic ecological system and to a rather long period of its re-adaptation.

4. The analysis of possible influence of low-frequency radiation requires three types of effects to be taken into account: injuring, annoying, and informational. The radius of the injuring effect of low-frequency radiation is limited to several tens of meters, and the radius of the annoying effect is within several kilometers from the source. The informational effect may extend over a large area in application to the mysteceti and certain fish species.

5. The informational effect, which is understood as some change of the regular informational conditions, may affect the

orientation, navigation, and, possibly, sounding. The effect can be both immediate or delayed.

6. An important factor of the influence of low-frequency radiation on marine mammals can be its effect on the food chain - mainly, on small-size fish. The problem of such influence needs further investigations both by studying the literature data and by performing the proper experiments.

7. The calculation of the distribution of the sound field produced by a source located in the point with coordinates 82.5 deg. north and 20 deg. east show that, if the sound levels of the source do not exceed 200 dB, the radiation practically does not penetrate to the Barents Sea and decays during the propagation through the Franz-Victoria trough.

4. RECOMMENDATIONS concerning the applications of low-frequency radiation in the East Arctic Region and statements of research projects.

#### The radiation mode

1. We recommend the following mode of radiation: during the first 5 min, the radiation level should increase gradually and reach its maximum, which exceeds the normal radiation level, then the radiation level should be brought to the optimum one. We assume that such initial stage will allow the animals to leave the zone of the injuring effect, and radiation of the maximum amplitude signal will serve as a warning for the animals, who stay in the zone of the annoying effect.

2. The temporal structure of the signals being radiated must be much different from the time parameters of the typical signals of marine mammals. We suggest alternation of 20 - 30 min continuous signals with extensive pauses.

3. We do not recommend to apply signals, which consist of several harmonics, because this kind of sounds are typical for the acoustic communication of certain species of the mysteceti whales (right whale, minke, grey whale).

4. It is desirable, for the purpose of warning, to use low-frequency signals of the same frequency and duration as the intended radiation, but of lower levels, so that all species, who rece-

ived this signal, could leave the zone of the deteriorating effects.

#### Full-scale studies in the zone of low-frequency radiation

1. It is necessary to perform a biological monitoring and acoustical control before the beginning of radiation, during the radiation, and after the termination of low-frequency radiation by making a biological survey of the water using a research vessel, visual and acoustic systems of observation of the marine mammals behaviour.

2. During the period of experimental operation of the radiating system, labelling of several animals of different species of cetaceans and pinniped should be done in order to trace them by telemetric systems using the satellite communication.

3. Special tracing of such animals as fin whale should be done by changing the frequency and the time characteristics of the radiation in such a way that they could approach the characteristics of the communication sounds.

#### Laboratory-scale experiments

1. The development of the technique and the performance of the experiments on the electrophysiologic evaluation of the parameters of low-frequency hearing in marine mammals by cordling of the evoked responses and (or) brain potentials reproducing the sound frequency.

2. The development of the technique and the performance of the experiments on the evaluation of low-frequency hearing of marine mammals by registration of the skin-galvanic reflex and (or) the reflex changes of the cordial rhythm.

3. Experimental study of the effect of intense low-frequency sound on hearing in aquatic and half-aquatic animals (fish, amphibian) by testing the hearing impairments by registration of the brain stem potentials.

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APPENDIX N 1

LEGISLATION DATABASE ON THE PROTECTION,  
REPRODUCTION AND RATIONAL EMPLOYMENT OF  
MARINE MAMMALS ( CETACEAN AND PINNIPED )  
IN THE ARCTIC REGION

The present document contains the synopsized list of the laws, decrees, edicts, resolutions, decisions and international agreements of the USSR and Russia from the beginning of twentieth up to the present time. All these documents were not cancelled by special decisions but they were only partially restricted and expanded by the Russian Federation Constitution and by the edicts of the President and the Government of Russia.

The Decree of the RSFSR People's Commissars Soviet "On the Protection of Fish and Animal Areas in the Arctic Ocean and in the White Sea" // The RSFSR Statute Book. - .May,24, 1921 N49 - Item 259.

The present decree granted the People's Commissariat of Food and the People's Commissariat of Marine Affairs the right to issue the instructions and to establish the rules of cetacean and pinniped animals hunting in the White Sea, Barents Sea, Kara Sea and in the other seas of the Arctic Ocean. The cetacean and pinniped animals hunting was allowed only for Russian citizens by special licences of GLAVRYBA. The mission of marine mammals protection was assigned to the Navy and the ranger troops of the RSFSR.

The Resolution of the Peoples's Commissars Soviet of the USSR "On the control of the fishing and protection of fish resources". // The USSR Satute Book - September, 25, 1935, - N50 - Item 420.

The present resolution provided the lease form of employment of all the water bodies where marine mammals hunting took place, including cetacean and pinniped animals hunting in the Arctic Ocean. Hunting was allowed only by special licences issued by GLAVRYBVOD authorities. The areas and the periods of hunting were normed.

The Order of the Minister of Fishing Industry of the USSR "On the Rules of Whaling" // The Ministry of Fishing Industry of the USSR. - January, 20, 1955 - N26 Items 1-12.

According to this Order the whaling of the Arctic right whales and grey whales was forbidden everywhere except for the right and gray whales hunting for the needs of Far North natives. The restrictions of the whaling on the age and sex of animals and on the season were imposed also. The responsibility for the violation of these rules was provided. The mission of control was assigned to GLAVRYBVOD.

The RSFSR Soviet of Ministers Resolution "On the Actions of the Arctic Animals Protection". // The RSFSR Statute Book - November, 21, 1956 - 5, N738.

In particular, the cessation of walrus hunting in all the seas of the Arctic Ocean was provided starting from January, 1, 1957. The exclusion was made for the Far North inhabitants, for them walrus hunting was allowed for personal needs; the exclusion was made also for the participants of the polar expeditions.

The Resolution of the Soviet of Ministers of the USSR "On the Actions for the Ordering of the employment and the Protection of Water Resources of the USSR" of April 22, 1960 - N425 // The Resolutions of the Party and the Government on the economical matters. - 1960 - 4 - p.652-656.

The purpose of the Resolution is the ordering of complex employment and protection and the fast liquidation of water bodies pollution particularly the pollution of all the seas adjoining the USSR territory. Particularly attention was paid to the inadmissibility of unrefined sewage drainage to seas.

The Agreement between the Government of the Union of Soviet Socialist Republics and the Government of Norway "On the Actions on Seal Hunting Control and the Protection of Seal Resources in the North-Western area of the Atlantic Ocean". // Collection of International Agreements on Fishing. - Moscow, 1961.

The agreement dealt with right seals, hooded seals, walruses, bearded seals and ringed seals; it was directed to the stabilization of the fundamental seal species populations in the White Sea and in the Barents Sea.

The Agreement between the Government of the USSR and the Government of Finland "On Fishing and Seal Hunting", 1959. // Collection of International Agreements of Fishing. - Moscow, 1961.

The Agreement also deals with the questions of protection and rational employment of ringed seals in the Baltic Sea.

The International Convention on Whaling Control (Washington, December, 2, 1946) // Collection of International Agreements of Fishing. - Moscow, 1961.

The present Convention prohibited right and grey whales hunting in the Arctic Ocean.

The Moscow Treaty "On the Prohibition of Nuclear Weapons Tests in the Atmosphere, Space and Underwater // October, 10, 1963.



The present Treaty was directed to the prohibition of marine medium pollution and to the development of progressive industrial technologies which allow to cease the drainage of industrial waste to water.

The Edict of the Presidium of the Supreme Soviet of the USSR "On the USSR Continental Shelf". // The USSR Statute Book. February, 6, 1968 - 4 - P.549-551.

The present Edict was issued for the purpose of the development of natural marine mineral resources, it provided the protection of marine living resources from the harmful wastes of industrial enterprises. The Edict also covers cetaceans and pinnipeds in the Arctic Ocean.

The Appendix of the Order of the USSR Minister of Fishing "The Temporal Rules of Protection and Marine Animals Hunting for Soviet Ships, Organizations and Citizens" // MINRYBKHOZ of the USSR, September, 10, 1969, P. 1 - 15.

According to this Order the objects of protection and hunting in Russian area of the Arctic Ocean were the following animals: the right seal, the bearded seal, the ringed seal, the hooded seal, the grey seal, the beluga whale, the white-sided dolphin and the bottle-nose dolphin. The rational employment of these animals was carried out by the authorities of fish protection according to the international agreements. The temporal rules provided the types, areas, periods, instruments and the methods prohibited for hunting and the restrictions of seal and hooded seal hunting. Besides that starting from 1970 these rules prohibited hooded seal hunting in the White Sea and grey seal hunting in the Barents Sea and in the White Sea.

The Resolution of the Soviet of Ministers of the USSR "On the Order of Works in the USSR Continental Shelf and on the Protection of its Natural Resources"

July 18, 1969 // The Resolutions of the Party and the Government on Economical Questions, 1969 - 7 - P. 498-501.

The present Resolution was issued for the purpose of the rational employment of natural resources of the USSR continental shelf and it establishes a number of additional measures for preventing illegal hunting including cetaceans and pinnipeds living in the Arctic Ocean.

The Law of the Union Of Soviet Socialist Respublic "The Fundamentals of Water Legislation of the USSR" // The USSR Statute Book - December, 10, 1970 - 4 - p. 252-267.

The present Law controls a wide complex of relations in the interests of national economics, it provides some measures preventing water pollution including the marine living medium of arctic marine mammals. Particular attention is paid to the determination of the areas of marine constructions building which can have negative influence on marine animals including cetaceans and pinnipeds, the creation of perspective set of reserves to protect the especially valuable species of marine animals.

The Resolution of the Soviet of Ministers of the USSR "On the Enforcement of Nature Protection and on the Improvement of Nature Resources Employment" December 29, 1972, N 898. // The USSR Supreme Soviet Register - 1972 - N 39 - Item 464.

The present Resolution provides a number of actions directed to the maximal prevention from the negative influence of the economical activity upon the environment and to the solution of the problems of nature protection and rational employment of natural resources including the resources of marine mammals in the Arctic region.

The Resolution of the Soviet of Ministers of the USSR "On the Additional Measures for the Development of Economics and Culture in the Areas of Far North and in the areas equated with them" December 25, 1973, N 927 // Collection of Normative Acts - 1979 - 2 - p. 143-146.

The Resolution is directed to the development of Far North natural resources and it charges MINRYBKHOZ of the USSR to gather marine animals meat and to deliver it to fur-farms of the Far North.

The Resolution of the Soviet of Ministers of the USSR "On the Reinforcement of Control of Sea Pollutions by the Substances Harmful for Peoples Health and for Marine Animal Resorces". February 14, 1974 // The USSR Statute Book - 1974 - 4 - P. 314-315.

The present resolution is issued to reinforce the control of marine medium pollution and the protection of marine living resources including cetaceans and pinnipeds but the scope of the Resolution does not cover the ships of Navy.

The Resolution of the Soviet of Ministers of the USSR "On the Reinforcement of the Protection of Valuable Species of Fish, Marine Mammals and Marine Animals in Water Bodies of the USSR" October 25, 1974. N 833.

The present Resolution covers cetaceans and pinnipeds of the Arctic Ocean and gives the summation for the given moment of the numerous fishing rules applied to the protection and rational employment of marine mammals.

The Convention on the Protection of Marine Medium in the area of the Baltic Sea, March, 1974, Helsinki.

In the Convention the considerable attention is given to

the protection of the areas of living of ringed and right seals in the area of the Baltic Sea. The Convention was signed by the USSR and its undertakings were prolonged for Russia.

The Order of the Minister of Fishing of the USSR on the confirmation of "The Rules of Protection and Marine Mammals Hunting". // MINRYBKHOZ of the USSR - July, 11, 1975 - N300 - p.1-24.

The objects of protection and rational hunting in the seas adjoining the RSFSR territory were the following animals: the right ( White Sea ) seal, the ringed seal, the bearded seal, the grey seal, the white-sided seal. The sports and amateur marine animals hunting was prohibited in the Soviet Arctic Region everywhere and during the whole year except for walrus, seal and Beluga whale hunting for the personal needs of the Far North natives. Right seals, hooded seals, ringed seals hunting was strictly limited and controlled by GLAVRYBVOD.

The Resolution of the Soviet of Ministers of the USSR "On the Measures on the Reinforcement of the Protection of the Baltic Sea from Pollution" // The Resolutions of the Party and the Government on Economical Questions. - 1976 - 11 - p.389-394.

The present Resolution was carried out for the purpose of the preservation of the Baltic Sea from pollution and to provide the protection of natural conditions complex in the Baltic Sea coastal areas, which deals with the improvement of the living medium of seals and white-sided seals Baltic population.

The Regulationis of Fish and other Living Resources Protection in the Sea Areas Adjoining the Cost of the USSR of February 25, 1977 // The Resolutions of the Party and The Government on Economical Questions.

- 1977 - 11 - p. 647-650.

The present Regulations charges the authorities of fish protection and the ranger troops to carry out the protection of marine mammals in the Arctic region on the basis of other laws of the USSR and it was directed to the control of the actions of foreign persons and organizations hunting in sea areas.

The Resolution of the Soviet of Ministers of the USSR "On the Introduction of the Temporal Measures of Living Resources Protection and Fishing Control in the Regions of the Pacific Ocean and the Regions of the Arctic Ocean adjoining the Coast of the USSR. // The USSR Statute Book - February, 24, 1977 - 4 - P. 539-450.

The Resolution deals with the establishing of protection measures in the 200-miles sea zone including the Arctic Ocean, these measures covers marine mammals living there.

The Resolution of the Soviet of Ministers of the USSR "On the Additional Measures to Reinforce the Protection of Nature and to Improve the Employment of Nature Resources of December, 1, 1978. // "Pravda" newspaper, of January, 6, 1979.

The Resolution is directed to the elimination of the defects of reserves organizing and animals protection including marine mammals of the Arctic Region. Particular attention is given to the introduction of progressive technologies decreasing harmful industrial ejections into environment.

The Law of the Union of Soviet Socialist Republics "On the Protection and Employment of the Animal Kingdom" // "The News of People's Deputy Soviet of the USSR" June 25, 1980, P.1-24.

The present Law covers all the natural resources of the continental shelf of the USSR including marine mammals of the Arctic Ocean. In the Item 3 the animal kingdom (including marine mammals) are declared to be state property. In the Item 8 for the first time the statements of the species variety protection, the protection of living medium and the control of animals populations were formulated as priorities for the purpose of human protection. In the Item 11 the statements on marine mammals hunting and on the periods and places of extracting them from nature are formulated. The Items 13 - 19 charge employers to carry out measures on nature protection to observe the actual rules of protection at marine mammals hunting and to count up the populations of them. The Item 21 introduces as one of the most important measures of marine mammals protection the organization of reserves and preserves and specially protected zones. For the purpose of rare species protection and the species in danger of disappearing the Item 26 provides the strict rules of hunting. The Item 35 establish the departmental control of the protection and employment of marine mammals.

The Order of the Minister of Fishing of the USSR "The Rules of Whaling for Soviet Ships" September 26, 1980, N 435.

The Order establishes the additional restrictions along with the restrictions introduced earlier which cover cetaceans in the Arctic Ocean.

The Resolution of the Soviet of Ministers of the USSR "On the Measures to Reinforce the Protection of the Seas, the Rivers and other Water Bodies of the Arctic Region from Pollution. // The USSR Statute Book - January, 15, 1981 - 4 - Items 320 - 322.

The present Resolution charges to carry out the measures on the maximal reduction and ceasing of unrefined sewage

ejection into the seas of the Arctic region which directly influences on the state of cetaceans and pinnipeds living medium.

The Edict of the Presidium of the Supreme Soviet of the USSR "On the Economical Zone of the USSR". // The Register of the Supreme Soviet of the USSR - Ferbruary 28, 1982 - N 9 - Item 137.

The Edict charges the authorities of fish protection and the ranger troops to protect the economical zone of the USSR, they are also charged to control the protection and rational employment of the resources of the animals kingdom including marine mammals of the Arctic Ocean.

The Order of the Minister of Fishing of the USSR "On the Red Book of the USSR". August 16, 1983, N 380 // Orders Table of the USSR - 1983 - 1, N 12 - Item 56.

The present Order deals with the natural resources of the continental shelf of the USSR including marine mammals of the Arctic Ocean. In the Order it was particularly noticed that the hunting export and import of marine mammals can be carried out in some exceptional situations by special licences and the GLAVRYBVOD was charged to introduce the special changes of the actual fishing Rules and the Rules of marine mammals hunting and the Rules of Whaling taking into account the additional requirements to rare animals protection. In particular, these changes were taken into account for a number of Arctic mammals species: the right whale^ the humpback whale, the blue whale, the white-sided dolphin, the monodon, the white-nose dolphin, the right hyperodon, the bottle-nose dolphin, the grey seal, the walrus, the hooded seals and other species.

The Edict of the Presidium of the Supreme Soviet of the USSR "On the Reinforcement of Nature Protection

in the Areas of the Far North and in the Sea Areas adjoining the Northern Coast of the USSR". // The Register of the Supreme Soviet of the USSR - November 26, 1984 - N 48 - Item 863.

The purpose of this Edict is to reinforce nature protection in the areas of Far North and it provides more strict requirements to human economical activity in the coast and in the islands, that indirectly influences on the improvement of the state of cetaceans and pinnipeds inhabiting areas.

The Resolution of the Supreme Soviet of the USSR "On the Observation of Legislation Requirements on Nature Protection and Rational Employment of Natural Resources" July 3, 1985 // The Register of the Supreme Soviet of the USSR - 1985 - N 27 - Item 479.

The present Resolution is directed to the additional measures on nature protection and rational employment of natural resources through the reinforcement of the control of the observation the rules of the USSR legislation and through the reinforcement of nature protection measures promotion. The Resolution deals also with the problems of protection and rational employment of the whole animals kingdom including cetaceans and pinnipeds of the Arctic Region.

The Order of the Minister of Fishing of the USSR "On the Regulation of Administrative Responsibility for the Violation of the Laws on the Animals Kingdom Protection and Employment" August 14, 1985, // The Register of the Supreme Soviet of the USSR - 1985 - N 34 - Item 614.

The purpose of the present order is to reinforce the responsibility for the violation of the USSR laws on the animals kingdom protection and employment including marine mammals of the Arctic Ocean. Particularly the fines for any



damage to rare species of animals were reinforced.

The Order of the Minister of Fishing of the USSR  
"On the Registration "The Rules of Marine Mammals  
Protection and Hunting" // MINERYBKHOZ of the USSR -  
June 30, 1986 - N 349, P. 1-16.

The area covered by the present Rules includes all the seas of the Arctic Ocean adjoining the RSFSR territory. The objects of protection and hunting are all the seals, walruses and dolphins inhabiting in these areas. The control of all the marine mammals protection and hunting as formerly is carried out by the GLAVRIBVOD. In addition to the restrictions established earlier the hunting prohibition of the grey seal, the walrus, the hooded seal, the wide-sided dolphin, the grey dolphin, the white-nose dolphin registered in the Red Book of the USSR and in the Lists of the Convention of the international trade of the species of wild flora and fauna which are in danger of disappearing. As an exception bearded seal net hunting was allowed. Bearded seal hunting for the peoples of the Far North in the White Sea is restricted by period - from November, 1 to April, 1 and in the Barents Sea and in the Kara Sea from October, 1 to April, 1.

The Order of the First Deputy of the Chairman of the GOSAGROPROM of the USSR "On the Registration of the Red Book Regulations of the USSR" May 12 1987, N 380 // GOSAGROPROM of the USSR - 1987 - p.1-6, Appendix 6 p.

The Order establishes the special Order of issuing of licences for the animals registered in the Red Book hunting, catching and gathering including the marine mammals of the Arctic Ocean.

The Edict of the President of Russian Federation  
"On the Protection of Natural Resources of the Territorial Waters, the Continental Shelf and the Economical Zone of Russian Federation" May 5, 1992. -

N 436.

The present Edict declares the unpermitted managing of natural resources in territorial waters, continental shelf and economical zone of the Russian Federation as impermissible action, it requires to provide the protection of these areas according to the requirements of actual legislation. The Edict covers the Rules of marine mammals protection and hunting including marine mammals of the Arctic Ocean.

The Resolution of Russian Government "On Licencing and Quoting of export and import of goods (works, servises) in the territory of Russian Federation" of November 6, 1992, N 1994.

The present Resolution regulates the export and the import of rare species mammals including the animals inhabiting in the Arctic Ocean.

The Resolution of Russian Government "On the Participation of the Russian Federation in the International Convention on Whaling Regulation" December 11, 1992 - N 967.

The Resolution charges to observe the order and the restrictions of whaling in the context of international obligations of Russia on the convention on international trade of wild fauna and flora species which are in danger of disappearing (CITES).

The Resolution covers all the cetacean animals including the species inhabiting in the Arctic Region.

The Resolution of the Government of Russian Federation "On the Creation of United State System of Ecological Monitoring" November 24, 1993, N 1229 // Statements Collection - 1993 - 48 - Item 4661.

The Resolution provides the control of the state of

bio-resources in Russian Federation including the control of marine mammals of the Arctic Region.

The Resolution of the Government of Russian Federation "On the Registration of the Regulations on the Fishing Committee of Russian Federation". March 6, 1993, N 208 // Statements Collection - 1993 - 11 - Item 942.

The Resolution modifies the system of marine bio-resources control ( including marine mammals control ).

The Decree of the President of Russian Federation "On Federal Natural Resources" of December, 16, 1993, N 2144 // Statements Collection - Moscow - 1994 - P.9.

The Decree is directed to the differentiation of property and responsibility for natural resources and it covers marine mammals of the Arctic Region.

The Resolution of the Government of Russian Federation "On Special State Authorities on the Protection and Control of Animals Kingdom" of November, 4, 1993, N 1108 // Statements Collection - Moscow - 1993 - 45 - Item 4344.

The Resolution assigns the responsibility for animals kingdom protection and rational employment to the MINPRIRODA. The present Resolution also covers Arctic cetacean and pinniped animals.

The Resolution of the Government of Russian Federation "The Questions of the Ministry of Ecology and Natural Resources of Russian Federation". April, 5, 1993, N 279 // Statements Collection - Moscow - 1993 - 15 - Item 1282.

The Resolution charges the Ministry of Ecology rare

animals species control including the control of rare marine mammals of the Arctic Ocean.

The Resolution of the Government of Russian Federation "On the Registration of the Regulations of Interdepartmental Commission of Arctic and Antarctic Affairs and on the Complement of the Commission" of February, 22, 1993, N 158 // Statements Collection - Moscow - 1993 - 9 - Item 749.

The Resolution is directed in main to the regulation of Arctic bioresources control and to the intensification of the investigations in the Antarctic Continent. It deals directly with the problems of protection and rational employment of Arctic marine mammals resources.

The Resolution of the Government of Russian Federation "On the State Commission on the Environment and Nature Employment" of October, 7, 1993, N 1005 // Statements Collection - Moscow - 1993 - 41 - Item 3951.

The principal charges of the commisiion deals with the protection and the rational employment of marine mammals in the Arctic Region.

The Resolution of the Government of Russian Federation "On the Registration of the Agreement between the Counsel of Ministers - the Government of Russian Federation and the Government of the Kingdom of Sweden on the cooperation in the area of ecology". February 2, 1993, N 89 // Statements Collection - Moscow - 1993 - 6 - Item 528.

The Resolution deals the problems of protection of Arctic marine mammals inhabitation areas.

The Resolution of the Government of Russian

Federation " On the Creation of State Nature Reserve "Big Arctic Reserve" of the Ministry of Ecology and Natural Resources of Russian Federation". May 11, 1993, N 431 // Statements Collection - Moscow - 1993 - 20 - Item 1846.

The coast of this reserve is an inimportant area of whalruses inhabitation.

# APPENDIX II.

## Biologic-Geographic Characteristics of the Main Cetacean Species of the Barents Sea

Subordo MYSTICETI, Flower, 1864 [1, 2]

Familia Balaenopteridae Gray, 1864

\* \* \* \* \*

Genus Balaenopa Lacepede, 1804

Species	Geographic Distribution and Seasonal Migrations	Food, Behaviour, Maximum Depth of Diving, and Travelling Speed	Size, Mass, and Numbers
Fin Whale			
Balaenoptera physalus Linnaeus, 1758	No pronounced seasonal long-range migrations were registered in the North Atlantic. In March and April, the fin whales can be found near the Kola peninsula. In early July, some of the whales move to the east of the Barents Sea toward the coast of the Novaya Zemlya (sometimes, they visit the Gorge and the Funnel of the White Sea and seldom reach the Kara Sea). Considerable numbers of whales stay in winter far north, within the zone of the Gulf Stream (in the Barents Sea, the stream reaches the coast of Novaya Zemlya). Others are likely to move, in October - November, toward the coasts of Spain, Portugal, North and West Africa, and Bermudas (Fig. 1).	Macroplanktophagos. Food ration: crustacea, fish. The fin whales can be found, usually, singly or in small groups of 2 - 4 whales. In the regions of high food concentration, hundreds of whales can be found crowding together. The depth of diving is likely not to exceed 100 m (maximum - 200 m). The whales travel over far distances with the speed 12 - 13 miles per hour. A frightened whale makes 18 - 20 miles per hour.	The length is 18 - 19 m, the mass is about 50 tons. The number of whales in the east-Greenland herd, as it was registered in July, 1988, is about 1300 heads. In the "Red book MSOP" (1991), the fin whale was classified as one of the species being in jeopardy of their future existence.
Subspecies:			
B. ph. Physalus Linnaeus, 1758			

Species	Geographic Distribution and Seasonal Migrations	Food, Behaviour, Maximum Depth of Diving, and Travelling Speed	Size, Mass, and Numbers
Sei Whale			
<i>Balaenoptera borealis</i> Lesson, 1828			
Subspecies:			
<i>B. b. borealis</i> Lesson, 1828	Sei whales appear in the Barents Sea near the Spitsbergen and Medvezhii islands, and, sporadically - near the coasts of Murman and Novaya Zemlya (Fig. 2). The dwelling area covers the open sea regions, but their preference is given to the zone of the continental shelf. The time of migrations is not quite clear. Because the sei whale is more heat-loving than other Genus <i>Balaenoptera</i> , he comes to the cold waters later - in mid July - August. He is assumed to travel along the European and African coasts as far as 20 - 25 deg. lat. north.	In the North Atlantic, the sei whales feed on invertebrates. They are hunting usually mornings and evenings. They keep singly or in pairs and do not form any large shoals. The whale-fishers believe the sei whale to be the fastest among the whales, though, his travelling speed was not measured.	The size is varying from 13.5 - 14 to 18 m, and the mass is 14 - 20 t. These whales are the most numerous of all other whales species. In 1978, in the North Atlantic, their number amounted to 2.7 thousand heads.

Species	Geographic Distribution and Seasonal Migrations	Food, Behaviour, Maximum Depth of Diving, and Travelling Speed	Size, Mass, and Numbers
Minke Balænoptera acutorostrata Lacepede, 1804	<p>In the North Atlantic, this whale forms three populations with some conventional borders. In summer, the north-eastern population dwells in the Greenland and Barents seas, its northern border reaches the Spitsbergen and Medvezhii islands, and, in the east direction, this population approaches Novaya Zemlya. The dwelling area covers also the Murmansk coastal region and the White Sea gorge (Fig. 3). In summer, the whales are common in the fields of fattening near the shore (within the zone of the continental shelf). These whales are also common in the open sea (in the northern part of the Barents Sea). Annual formation of minke shoals is registered in the region of lat. 75 - 76 deg. north and lon. 30 - 35 deg. east. Migrations back to the south begin in October. In November, virtually all whales go to the temperate waters, where they stay in winter and breed.</p>	<p>This whale dwells in shallow-water gulfs and bays, this fact being reflected in his second name "the gulf whale". In October, before the beginning of migration, he is staying well offshore. His food is mostly fish, and, to a lesser extent, plankton-type crustacea and mollusca cephalopoda. In summer, during fattening, the whales usually hold together in small groups, pairs, or singly, but, in the areas of high food concentration, they gather in shoals of several tens or hundreds of heads. They can stay under the water surface no longer than 10 - 15 min.</p>	<p>The whales are 7 - 9 m long, and their mass is 7 - 9 t. Large numbers of whales were registered in the Barents Sea in June. They are the main object of whale-fishing in the eastern part of the Barents Sea and near the Spitsbergen and Medvezhii islands. The number of minke in the North Atlantic in 1990 was about 81.5 thousand heads (up to 125 thousands) and, according to other data, about 55 thousands (37 - 84).</p>



Genus Megaptera Gray, 1864

Species	Geographic Distribution and Seasonal Migrations	Food, Behaviour, Maximum Depth of Diving, and Travelling Speed	Size, Mass, and Numbers
Humpback Whale			
Megaptera novaeangliae			
Borowski, 1781			
Subspecies:	Some time ago, the humpback whales were common in the Barents Sea, near the coasts of Murman, Novaya Zemlya, cape Sv. Nos. and near the Cheshskaya inlet. Now, their occurrence is limited to rare encounters in the water areas of the Rybachii island and of the west Murman islands (Fig. 4).	The food consists of pelagic and some of the bottom-dwelling animals: crustacea and fish. The humpback whales make no large shoals, they prefer to keep in groups of two or three animals, but may crowd in large numbers in the places of high food concentration. They can stay underwater no longer than 10 - 15 min. Maximum speed does not exceed 15 miles per hour.	The length is about 16 m and the mass is about 40 t. The record taken in June, 1988 in Norway and Barents seas and in the coastal regions of north Norway, Kola, and Spitsbergen provides the number of humpback whales about 1100.
M. n. novaeangliae, Borowski, 1781			

Familia Balanidae Gray, 1825

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Genus Eubalaena Gray, 1864

Species	Geographic Distribution and Seasonal Migrations	Food, Behaviour, Maximum Depth of Diving, and Travelling Speed	Size, Mass, and Numbers
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Balaena glacialis

Muller, 1776

Subspecies:	This whale may be seen from time to time near the Kola peninsula and Novaya Zemlya. The whales form two populations, one of them migrating in summer toward the coasts of Norway and Iceland. It is likely that the whales penetrate even farther north to the Barents Sea and Spitsbergen.	The food consists of small-size plankton, mostly crustacea. The whales can be found singles and, less frequent, in pairs or in groups of three whales. The travelling speed is 9 - 11 km/h; a frightened whale may swim as fast as 15 km/h. The whales of this species in the north-west Atlantic are able to produce numerous sounds.	The Balaena glacialis species is almost completely depleted by humans. In the "Red book MSOP" (1991), the status of E. glacialis was determined as being in jeopardy and, probably, going to disappear in the future. The average length of these whales is about 14 m.
E. G. Glacialis Muller, 1776			

Species	Geographic Distribution and Seasonal Migrations	Food, Behaviour, Maximum Depth of Diving, and Travelling Speed	Size, Mass, and Numbers
The right whale Balaena mysticetus Linnaeus, 1758	<p>The whale dwells in the north part of the Barents Sea, near Novaya Zemlya, Murmansk, and Vaigach island. He belongs to one of the four geographically isolated populations - the Spitsbergen's, which is located in the polar waters of Europe with the southern border at the latitude 61 - 62 deg. north. The life of these whales is related to the regions of sea ice. They can be found not only at the edge of ice, but also far away from it among the close drifting ice. It is likely, that the whales come to the Barents Sea from the Spitsbergen region after the ice there becomes less close. The time when the whales return from the Barents Sea (after the summer season is over) and their paths are unknown. The southern border of the whale distribution in summer depends on the location of the edge of the polar ice.</p>	<p>The food is microplanktonophagous. In the regions of fattening, the whales can be found singly, in pairs, or in groups of 3 - 5 animals. The minimum time they spend underwater is 2 - 3 min, and the maximum time is 25 min., on rare occasions - up to 80 min. The speed of a whale in a normal state does not exceed 7 km/h. An injured or frightened whale can develop a speed of 15 - 17 km/h. A distinctive feature of this whale species is the birth of calves in the cold water region or even in the zone of ice.</p>	<p>In the "Red book MSOP" (1991) this species is defined as being in jeopardy and possibly going to disappear in future. This whale is the largest in the family, his length is 15 - 18 m.</p>

Subordo ODONTOCETI [2 - 3]

Familia Delphinidae Gray, 1821

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Orcinus Fitzinger, 1860

Species	Geographic Distribution and Seasonal Migrations	Food, Behaviour, Maximum Depth of Diving, and Travelling Speed	Size, Mass, and Numbers
The Killer whale Orcinus orca Linnaeus, 1758	The coastal regions of Novaya Zemlya, the coast of Murmansk. The path and time of migrations were not studied, but it is known that in polar regions they can be found only in summer. The dwelling area covers both the coastal regions and the deep-water regions.	The beast of prey, eats warm-blooded animals and fish. Dives 2 - 5 min long. A pronounced herd instinct. The groups include up to 100 heads. The travelling speed during food migrations is 6 - 7 miles per hour. Maximum speed is about 17 miles per h.	His length reaches 8 - 10 m. Total numbers are unknown, but the species can be determined as valid for fishing.

Globicephala Lesson, 1828

Species	Geographic Distribution and Seasonal Migrations	Food, Behaviour, Maximum Depth of Diving, and Travelling Speed	Size, Mass, and Numbers
Globicephala melaena Traill, 1809	The south-east part of the Barents Sea including the water area near the Rybachi peninsula. The animals are likely to perform seasonal migrations, because, in the northern regions, they are more numerous in summer than in winter. In late summer, they are common in the west part of the Barents Sea and near the Medvezhi and Spitsbergen islands.	They eat large-size invertebrates and fish. Often form shoals of 1000 heads or even of several thousand heads.	Up to 8 m long. Comparatively abundant species.
Subspecies: G. m. melaena			

Familia Monodontidae

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Delphinapterus leucopede, 1804

Species	Geographic Distribution and Seasonal Migrations	Food, Behaviour, Maximum Depth of Diving, and Travelling Speed	Size, Mass, and Numbers
The beluga whale			
Delphinapterus leucas Pallas, 1776			
Subspecies:			
D. L. maris-albi Ostroumov, 1935	This whale is common near the Murmansk coast (mostly, in winter) and near the west coast of Novaya Zemlya. In early summer, most of the whales move from the Barents Sea to the summer pastures in the Kara and White seas. Some small shoals stay for summer in the regions of Cheshskaya inlet, Kolguev island, south end of Novaya Zemlya, Vaigach island, and Franz Joseph Land archipelago. This whale dwells in the coastal regions and can not be found in the open parts of the Barents Sea. In winter, he moves beyond the edge of ice and stays there among the drifting ice. Some small groups of whales were registered in large water patches in the midst of stable ice fields.	The food is fish (pelagic) and crustacea. This is a typical gregarious animal - forms groups of 2 - 4, 5 - 8 animals, rare singles in shoals of ten (5%) or several tens heads (26% of all cases). Seldom, herds of several hundreds heads can be observed (3% of all cases). During the periods of time of mass fish concentration, large herds of several thousands of heads can be found. When swimming, the animals usually stay under the surface for 20 - 40 s. They go no deeper than 8 - 10 m. But in certain cases, deep diving is possible down to several tens of meters. The time of diving is 3 - 5 min., but can be as long as 15 min.	The length of the adults reaches 250 - 380 m. The total number is estimated as 8 - 10 thousands. The most populated region seems to be the south-east end of the Barents Sea (all year long).

Monodon Linnaeus, 1758

Species	Geographic Distribution and Seasonal Migrations	Food, Behaviour, Maximum Depth of Diving, and Travelling Speed	Size, Mass, and Numbers
Monodon monoceros Linnaeus, 1758	Near Novaya Zemlya at 76 deg. lat. north (the Russian Harbour) and near the Franz Joseph Land archipelago. The southern borderline of the population is the region of the edge of ice in winter. In summer, they move north and can be found beyond 80 deg, lat. Some visits to the south were registered (to the Murmansk coast, to the Pechora mouth). The animal usually keeps far offshore.	The food is mollusca cephalopoda and fish (to a lesser extent). Can be found usually in small groups or singly; large shoals are quite rare. The animal can stay underwater for a long time, then he emerges 8 - 9 times with approximately 3 s intervals.	4 - 6 m long. Total number is quite small. May be classified as a rare animal.

Familia Physeteridae Gray, 1821

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Physeter Linnaeus, 1758

Species	Geographic Distribution and Seasonal Migrations	Food, Behaviour, Maximum Depth of Diving, and Travelling Speed	Size, Mass, and Numbers
The Sperm whale Physeter catadon Linnaeus, 1758	The south part of the Barents Sea near the Murmansk coast, possibly, up to the Xanin peninsula at the east. The main factor determining the migration paths and how far they go to the cold waters is the Gulf Stream. The migrations are poorly studied. It is well known, that these whales spend the winter outside the Russian coastal region. In early spring they begin moving north. Some of them do not go beyond 50 deg. lat. north, others move farther. Some of the males, depending on the hydrologic and food conditions, can stay in the north during the winter season, but most of them return to the south.	They eat mollusca cephalopoda and fish. Most of the animals, of which the food of the sperm whales consists, belong to the deepwater regions. The sperm whales can stay underwater for an hour or longer (max. - 2 h). They are gregarious animals. In the breeding regions they hold together in groups of about 15 heads. Adult males, who do not take part in reproduction, are swimming singly. The whales can dive to 1000 m deep and over. The travelling speed of migrating whales is 5 - 7 miles per hour. The maximum speed is not likely to exceed 10 miles per hour.	The adult males can be 14 - 15 m long. There are no data known concerning the whales numbers.
Subspecies: Ph. c. catadon Linnaeus, 1758			

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